TLRS-1 ; SYSTEM UPGRADE AND PERFORMANCE RESULTS

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ABSTRACT

A major system upgrade was undertaken in TLRS-1 to improve the ranging accuracy as well as to eliminate the biases observed during collocation with Moblas-4 & -8. The goal is to obtain collocated Lageos passes with Moblas-7 at the sub-cm level with calibration and satellite data residual RMS values of ~1 cm and comparable ground calibration data. Recent operational results show satellite and ground data close to the projected performance. In this paper we overview past system bias characteristics, causes for the bias and engineering upgrades accomplished to meet the goals.

1.0 INTRODUCTION

The collocation of TLRS-1 (Transportable Laser Ranging System) with MOBLAS-4 in Monument Peak and MOBLAS-8 in Quincy, California, during Sept. 1984-July 1985, revealed an azimuth dependent bias of approximately 10cm. Extensive investigations were carried out by the crew in the field with external help to identify and correct the problem to no avail. Hence the NASA Crustal dynamics program decided to bring the system to Goddard Optical Research Facility for detailed engineering evaluation and analysis by Bendix Engineering group and to make appropriate modifications to the system so as to reduce the bias to the 1-cm level.

2.0 COLLOCATION RESULTS FROM QUINCY AND MONUMENT PEAK

Fig.1 illustrates the bias as a function of azimuth angle. It is evident that the data shows a transition to 1.0 cm bias in the azimuth angle range of 30 - 210 degrees ("frontside"), and is close to zero in the range of 211 - 29 degrees ("backside"). An important feature to recognize here is the difference in the nature of the bias when the mount is switching from "backside" to "frontside" mode.

3.0 ENGINEERING EVALUATION

The AZ-EL mount of TLRS-1 has a 2 feet lever-arm and this produces two equivalent orientations for the mount which are mutually realizable by azimuth rotation of 180 degrees and elevation rotation of twice the angle with respect to zenith. These two equivalent orientations are known as backside and frontside modes. The mount can exhibit few mm of optical path length difference depending on the orientation. The magnitude of the observed bias was too large to be a consequence of the mount orientation. However, if the optical alignment of the system is such that the beam shifts at the field of view of the telescope depending on the orientation, this can produce significant bias if the detector is sensitive to the spatial positioning of the beam.

For optoelectronic detection of the received signal from the satellite the system had a high quantum efficiency Varian photomultiplier tube as the detector. Laboratory experiments have shown that the tube can exhibit 6-8cm time-walk even for few mm of spatial displacement of the beam on the photocathode. The electron beam inside this tube has a cycloidal trajectory between dynodes due to the longitudinal electric field and hence the transit time is not space-invariant. The single largest contribution towards the bias could thus be attributed to the detector. The errors in calibration

path distances, discriminator calibration, nonlinearity in the TD811 time interval counter etc., may be considered as additional sources for the observed bias.

4.0 HARDWARE/SOFTWARE UPGRADES AND PERFORMANCE RESULTS

The need for hardware/software upgrade was imperative following the determination of the above problems. To verify that the data-loop hardware changes (Table-1) would accomplish the set objectives, horizontal ranging was performed on 8 targets. These targets were located to provide fairly uniform azimuth angle coverage and had ranges of 50-400 meters. Fig.2 illustrates the measured system delay as a function of azimuth angle for various targets. Each division on the horizontal axis is 15 degrees while that on the vertical axis is 50ps (~7.5mm). Measurements were performed on the front and backside modes. As can be seen from the plot the azimuth dependence was not more than 6mm and is within the uncertainty of the hardware and survey measurement. The mean difference between the front and backside mode was less than 2mm and the upgraded hardware thus should meet the projected goals.

Table-1 illustrates the hardware configuration before and after the upgrade. Major software upgrade was also necessary for hardware interface, system diagnostics, shot-shot measurements of system parameters, and real-time computation/display of the statistics of ranging. A new analytical mount model was also developed to provide smoother alignment and tracking capability and is expected to become operational in the near future.

The system has been subjected to extensive ground testing prior to the commencement of collocation to meet collocation prerequisites. These tests included cube map, system stability as a function of time, range, signal amplitude , temperature and azimuth. These results are displayed in Fig.3-6 and it is clear that the system is capable of providing sub-cm collocation data.

Collocation is presently underway at Goddard Optical Research facility between TLRS_1 and MOBLAS_7 and the initial results are meeting the sub-cm criteria and look very encouraging. More collocated passes are to be taken and analyzed and the results will be published at a future time.
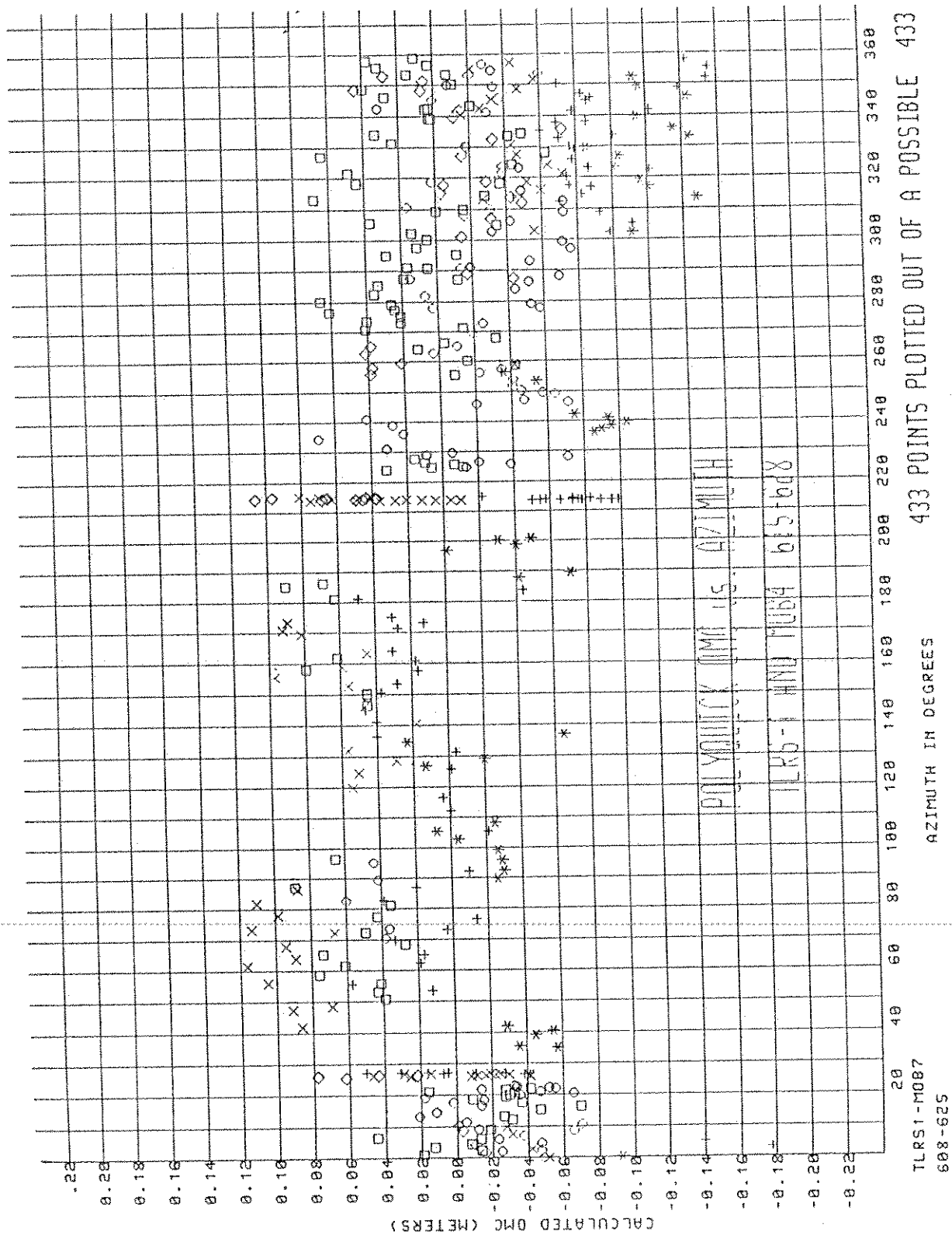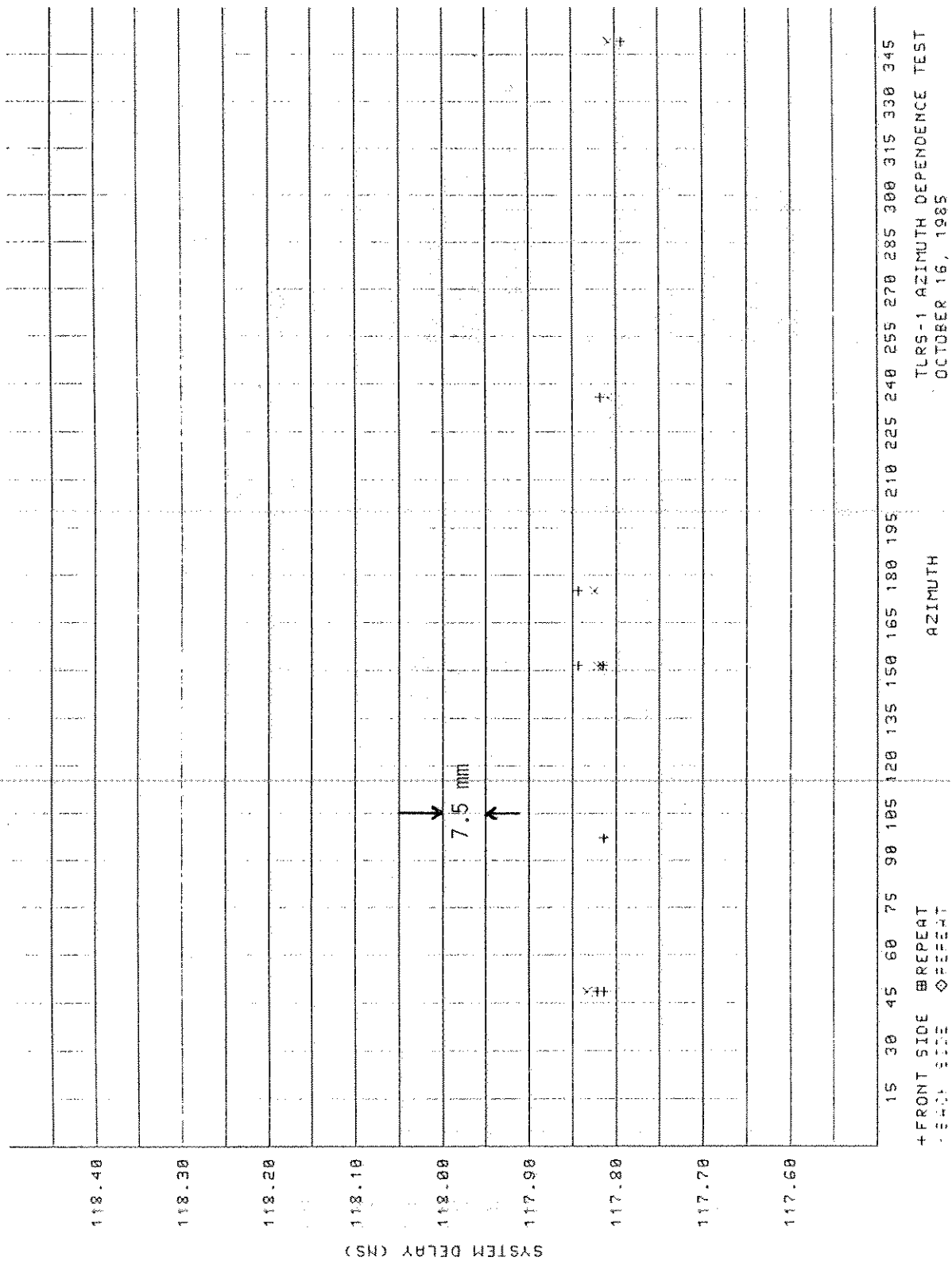
433 POINTS PLOTTED OUT OF A POSSIBLE 433

POLYANITK DMC vs. AZIMUTH

TLRS-1 AND MOBA PASS 619

TLRS1-M087
608-625

AZIMUTH IN DEGREES

20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360

CALCULATED DMC (METERS)

.22 0.20 0.18 0.16 0.14 0.12 0.10 0.08 0.06 0.04 0.02 0.00 -0.02 -0.04 -0.06 -0.08 -0.10 -0.12 -0.14 -0.16 -0.18 -0.20 -0.22

FIG. 1

FIG. 2

TLRS-1 SYSTEM CONFIGURATION

	BEFORE UPGRADE	AFTER UPGRADE
LASER		
OUTPUT ENERGY	QUANTEL YG441ML	QUANTEL YG402DP
	4 mJ	100 mJ
PULSE WIDTH	200 PICOSECONDS (PS)	200 PICOSECONDS (PS)
PULSE RATE	5 PULSES PER SECOND (PPS)	5 PULSES PER SECOND (PPS)
RECEIVE ELECTRONICS		
PHOTOMULTIPLIER TUBE	VARIAN	ITT MICROCHANNEL PLATE
DISCRIMINATOR	ORTEC 934	TENNELEC TC 454
TIME TO DIGITAL CONVERTOR	TD 811	HP 5370B
DETECTION	SINGLE PE	SINGLE PE
OPTICAL SYSTEM		
TELESCOPE	25 CM REFRACTIVE	SAME

TABLE 1

• TRACKING MOUNT		
- TYPE	AZ-EL (U. OF TX DESIGN)	SAME
- ENCODER RESOLUTION	2^{22} (.31 ARC SEC)	SAME
• TIMING ELECTRONICS		
- SHORT TERM STANDARD	CESIUM	SAME
- EPOCH STANDARD	LORAN RECEIVER	GPS RECEIVER (TRIMBLE)
• COMPUTER		
- HARDWARE	NOVA	SAME
- SOFTWARE	U. OF TEXAS	U. OF TEXAS + BFEC
• CALIBRATION	INTERNAL CALIBRATION (INSENSITIVE TO POSSIBLE MOUNT BIASES)	EXTERNAL + INTERNAL
• ENVIRONMENTAL CONTROL		
- TEMPERATURE	CONTROLLED BUT	70 $\pm$ 5°F
- HUMIDITY	RANGE UNKNOWN	50% $\pm$ 10%

TABLE 1 (CONT'D.)

CUBE MAP ON TARGET #1 FROM VLPS 1

JULY 28, 1996

3 mm

10.8
10.78
10.76
10.74
10.72
10.7
10.68
10.66
10.64
10.62
10.6
10.58
10.56
10.54
10.52
10.5

1   2   3

☐ SYSTEM DELAYS

F I G. 3
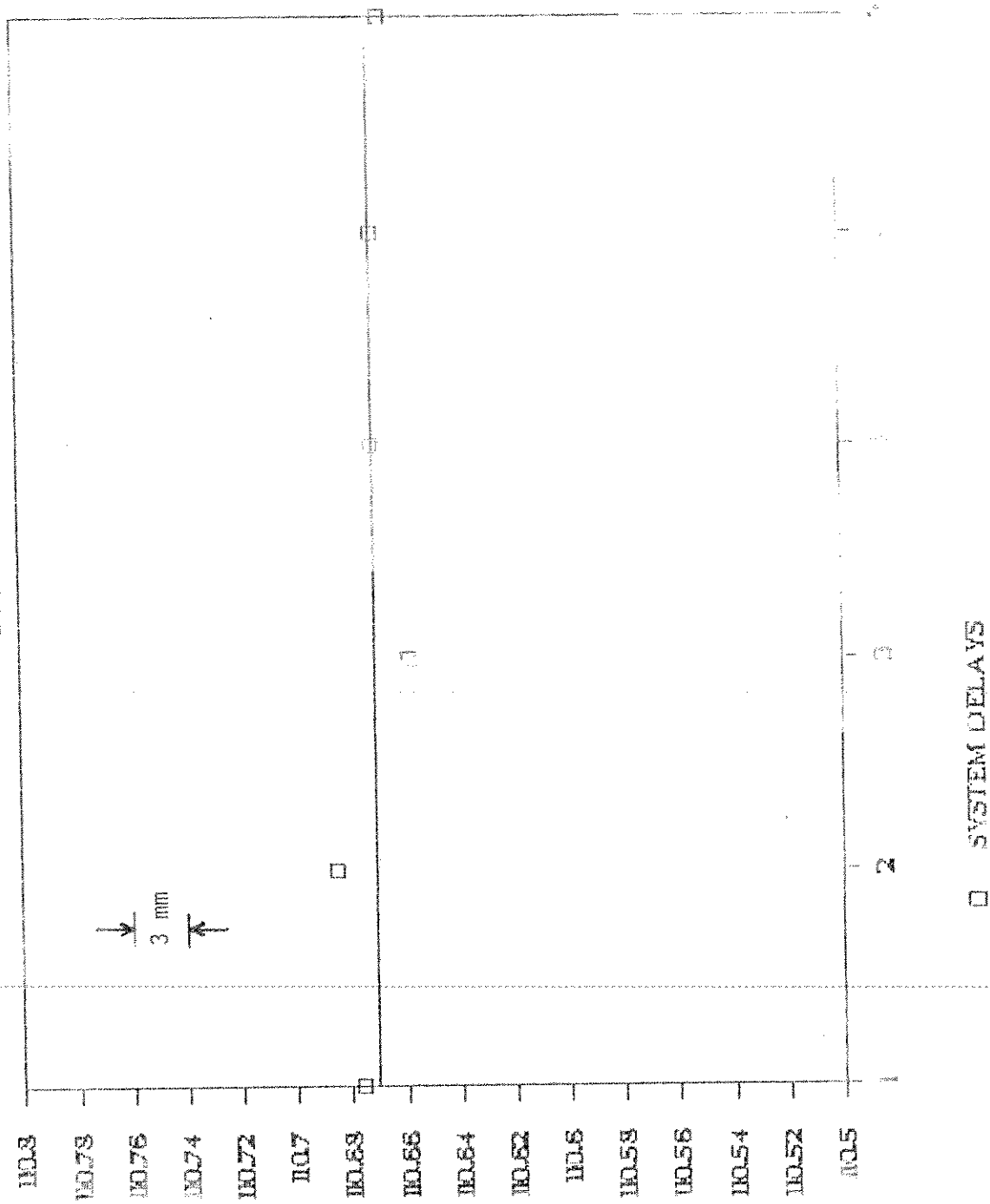
STABILITY TEST OF TIPS 4 ON TARGET #4

JULY 26, 1995

1.5 mm

□ SYSTEM DELAYS
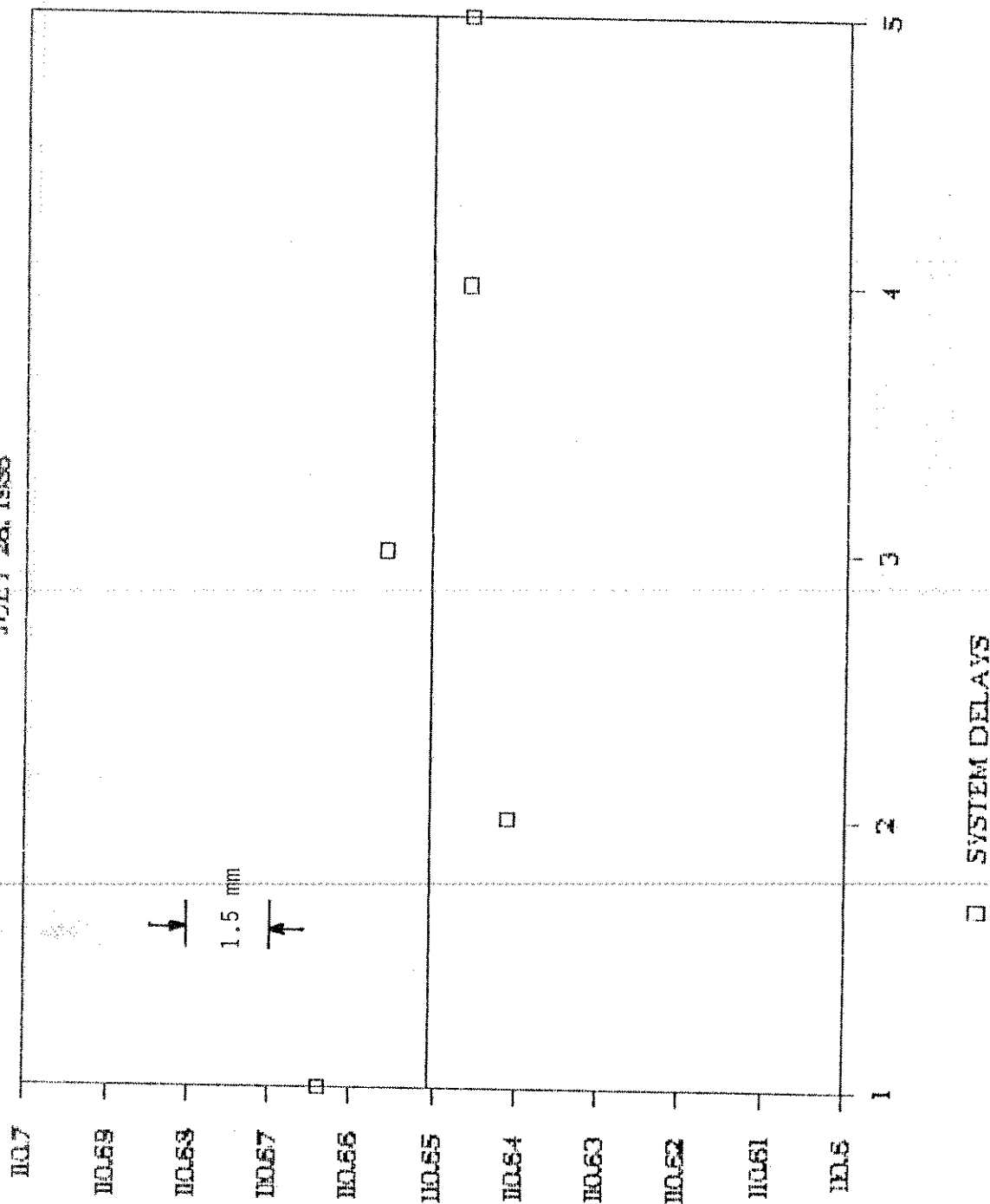
FIG. 4

MULTITARGET RANGE STABILITY

JULY 25 - 27, 1996

□ SYSTEM DELAYS (ns)
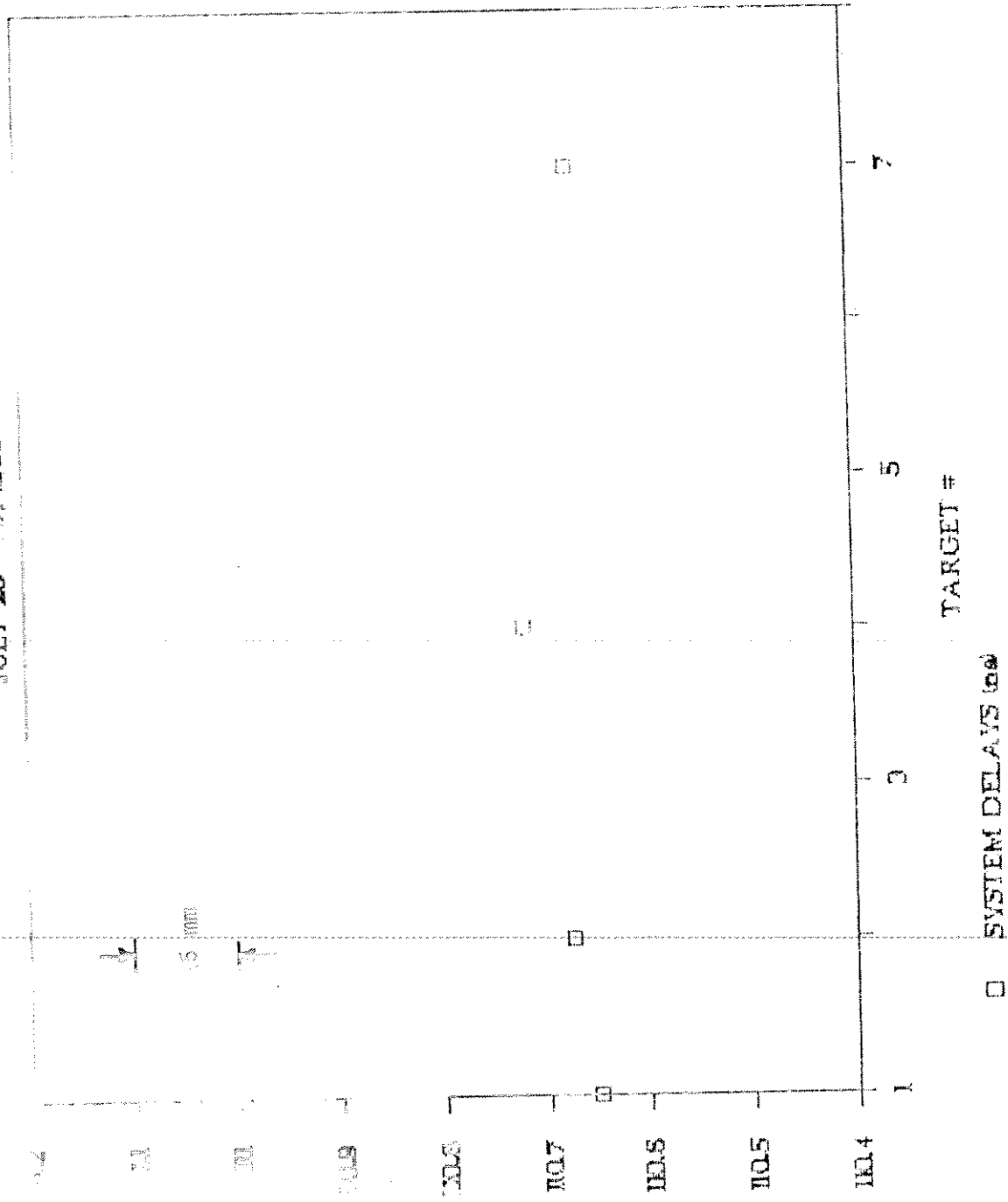
TARGET #

FIG. 5

AZIMUTH DEPENDENCE (FOUR TARGETS)
JULY 26 - 27, 1995
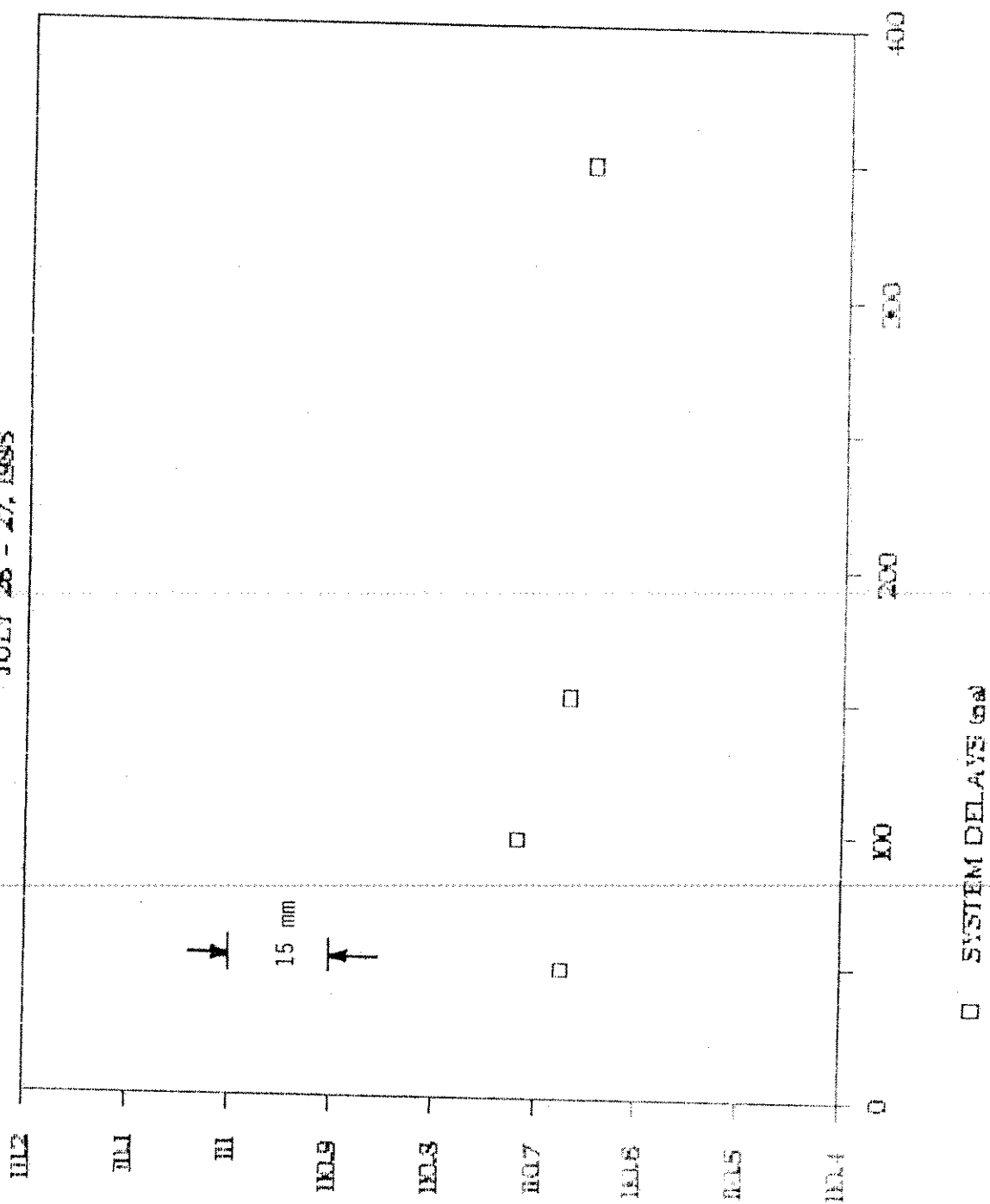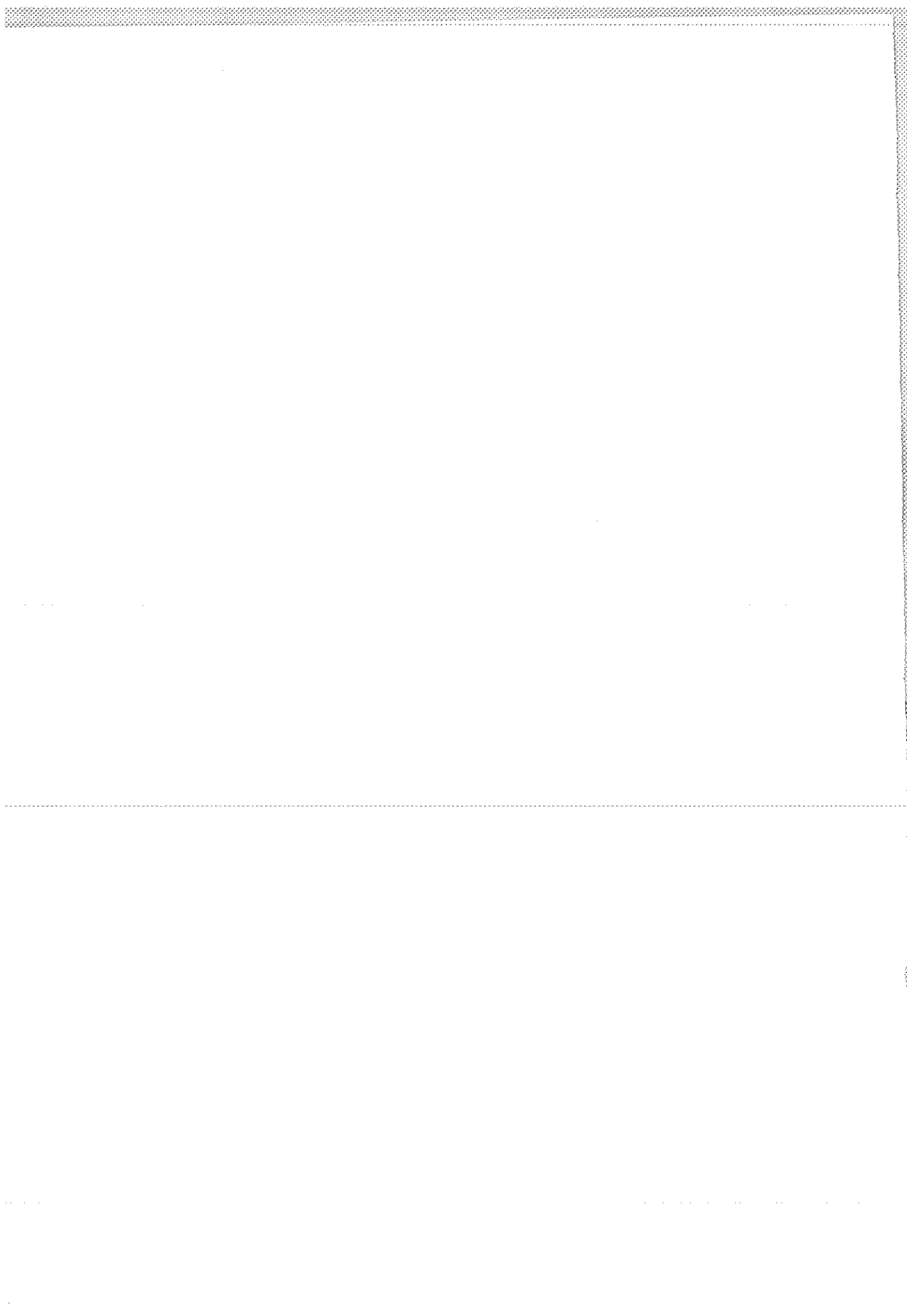
□ SYSTEM DELAYS (ns)

FIG. 6

SATELLITE LASER RANGING SYSTEM AT THE SIMOSATO HYDROGRAPHIC OBSERVATORY AND THE TRANSPORTABLE SYSTEM ; HTLRS

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ABSTRACT

The paper outlines the history of laser ranging in Japan, and introduces the SLRS installed in the Simosato Hydrographic Observatory of Hydrographic Department, Maritime Safety Agency. It also describes the transportable system ; TLRS now under development for determining the locations of isolated islands around Japan.

45

INTRODUCTION

The work on laser ranging in Japan began with an experiment of ranging the GEOS and DIADEME satellites at the Dodaira Station of Tokyo Astronomical Observatory (TAO) in December 1968. A satellite laser ranging system (SLRS) using a receiving telescope with diameter of 60 cm, and a ruby laser with pulse width of 50 ns, output of 1 J, 1 pps, was manufactured for the experiment[1][2].

A lunar ranging experiment was made at the Okayama Astrophysical Observatory in 1971 with the target of the retro-reflector installed by Apollo 11 on the surface of the moon. The experiment employed an astronomical telescope with diameter of 188 cm as the transmitting and receiving optics, and a ruby laser with output of 5 J, 12 ppm[3][4]. Above two systems were developed by TAO and Hitachi.

The work of TAO has since been continued at the Dodaira Station, and the system was improved several times.

A test model of an SLRS for geodetic observation was built up jointly by the Hydrographic Department (JHD) of Maritime Safety Agency (MSA) and Geographical Survey Institute (GSI) and installed at the Kanozan Geodetic Observatory in 1976. The system employed a receiving optics with diameter of 40 cm, a ruby laser, and a three-axis mount[5].

Upon reviewing the experiment results and the world's technological trends, the JHD decided to use an SLRS for marine geodetic control, and to determine the locations of isolated islands around Japan. The JHD introduced a fixed type SLRS for the base station into the Simosato Hydrographic Observatory (SHO)[6].

The SLRS is of the same size with the system of the IFAG station in West Germany. It is provided with a receiving telescope, 60 cm in diameter, and an Nd-YAG laser having a pulse width of 200 ps, 4 pps.

Japan's first geodetic satellite "AJISAI" which means "HYDRANGER" of flower in Japanese was launched on an orbit on August 12, 1986(UT), by the first H-1 rocket which was developed by the National Space Development Agency (NASDA).

Following the introduction of the fixed type SLRS, the MSA has started developing a transportable SLRS:TLRS which is intended for determining the locations of isolated islands in combination with the satellite "AJISAI". The TLRS, now being manufactured by Hitachi Limited, is expected to be completed in October 1987.

THE SLRS AT SIMOSATO

The laser site of the Simosato Hydrographic Observatory is situated close to the point of Kii Peninsula of Honshu Island (135° 56 min. E, 33° 34 min.). The site, at an altitude of 60 meters above the sea level, faces the Sea of Kumano. With annual precipitation of more than 2,700 mm, the climate is not so suitable for satellite ranging.

The SLRS at Simosato was manufactured jointly by GTE of the U.S.A. and Hitachi of Japan under the supervision of JHD. GTE manufactured the laser, optics and mount, control and data-processing equipment subsystem, and main software. Hitachi took the roles of manufacturing the timing system, the system calibration equipment including the ground target, various types of support software for operation and data processing,

and of integrating, installing and adjusting the entire system.

The SLRS was brought into the Simosato site in February 1982. Regular observation was started in April after some adjustment and testing. Since then, the SLRS has been continuously operating for four years to date.

Figure 1 shows an external view of the entire Simosato station. The SLRS installation is housed in the building on the right side. Figure 2 shows the electronics including the control and data-processing equipment subsystem. Figure 3 shows the optics and mount.

Table 1 lists the main items of the system specification.

During the discussions on the proposed SLRS installation at Simosato, those who concerned with the project were afraid that satisfactory observation might not be performed at the low-altitude, seashore site, where the climatic conditions are not favorable for the purpose. Table 2 lists the results of the observation during the past four years, which indicate that the number of annual data acquisitions has been increasing. Ranging data of 297 passes and 243,800 ranges was acquired for the LAGEOS in 1985.

System operation and ranging of LAGEOS, STARLETTE and BEACON-C is conducted around-the-clock by five staff members headed by Mr. E. Nishimura. One of the ranging objects was changed from BEACON-C to AJISAI last August. Figure 4 shows the ranging data of AJISAI obtained immediately after its launching.

Hitachi has been contracting with JHD for the SLRS mainte-nance.

The coordinates of the base point at the SHO were estimated from the satellite ranging data obtained at the Simosato site, and were reported[7],[8].

In addition to the main work for marine geodetic control, the JHD participates in the efforts to detect plate motions and crustal movements in the SLRS observation project which will contribute to estimating the earth rotation and geophysical parameters.

The following additions and changes were made to the SLRS:

(1) Laser attenuator

The ground target is used to calibrate the system delay time. An attenuator of the construction shown in Fig. 5 is added to the system in order to assure safety against the laser beam and to match the signal intensity with the level of the signal reflected by the satellite. A high attenuation ratio is obtained from the diffractive effect of a pin hole aperture and a beam splitter with high reflection ratio.

(2) Photomultiplier tube (PMT)

The static crossed field type photomultiplier tube initially employed for the system caused deterioration of the dynode gain in about two years after the start of its use, and needed to be replaced. However, the PMT was then out of production. Its substitute selected was the Micro channel plate PMT with gate. At the same time, a wideband amplifier (DC to 3.15 GHz) was added to the back of the PMT in order to

prevent the output from being saturated by the strong

background light in the daytime, and to improve the

signal level detectable by the system.

Its employment resulted in the increase in the data

acquisition rate and similar ranging accuracy to the

initial PMT, helped by the additional amplifier.

(3)   Software

Support software was developed and added to the main

software. The major items of the support software

include the satellite path charting feature for

observation scheduling, the star position computing

and tracking feature for correcting mount pointing

errors,the ranging accuracy calculating feature,

satellite position calculating feature using numeri-

cal integration method, and the joystick hold feature

for facilitating satellite tracking with offset

error.

Prior to the construction of the Simosato site, the one of

authors visited the laser sites of CERGA in France, IFAG in

West Germany, NASA Goddard, SAO Boston and Hawaii Haleakara in

the U.S.A. The authors wish to thank the personnel of these

organizations for their kind advice and useful suggestions.

TRANSPORTABLE SYSTEM; HTLRS

The transportable system: HTLRS the JHD plans to introduce is to be used for AJISAI satellite ranging to determine the locations of ten major isolated islands around Japan. Figure 6 shows these ten islands (marked with a double circle) where mobile observation is expected.

The observation is scheduled to be done on two islands a year. The SLRS will be transported by truck, by ship (cargo boat or ferry boat), or by aircraft.

To permit transportation by the above means, the entire system will be housed in two shelters as shown in Fig. 7 and designed to weigh less than five tons.

The optics/mount and the laser are assembled on the same bench. Upon arrival at the site, the bench is installed on a concrete pier constructed on the ground independently of the shelters. The electronics including the control and data processing equipment subsystem are housed in the other shelter.

Table 3 lists the major specifications of the system. Figure 8 is a block diagram showing the system configuration. The major target satellite of the HTLRS is the AJISAI. It is, however, designed to be capable of ranging the LAGEOS.

The ability of a ranging system is represented by the concept of system size[9]. The authors defined the system size parameter S for the SLRS as follows:

$$S = n \cdot E_0 \cdot A_r \cdot \alpha \beta \gamma \cdot \eta \quad \dots\dots\dots\dots\dots\dots\dots \quad (1)$$

where,

Table 2 Data Acquisition at Simosato Hydrographic
Observatory and Its Mean Range Accuracy

year	LAGEOS		STARLETTE		BEACON C		AJISAI	
	passes	ranges	passes	ranges	passes	ranges	passes	ranges
1982	47	11,000	36	4,700	59	11,900	–	
1983	137	30,000	116	29,400	199	92,200	–	–
1984	223	93,300	118	37,800	150	56,100	–	
1985	297	243,800	108	38,800	154	67,500	–	–
~Aug 1986	156	103,900	53	11,700	56	15,400	27	25,300
accuracy	9.0 cm		9.8 cm		9.2 cm			

n : Laser output repetitions

           Eo : Laser output energy

           Ar : Area of receiving optics

          αβγ: Efficiency of transmitting and receiving optics

            η : Quantum efficiency of detector.

Figure 9 shows the system size of the transportable SLRS

defined by the equation (1) above. The horizontal axis in Fig.

9 represents "S" in equation (1), while the vertical axis

shows the beam divergence of the transmitting laser. The

oblique lines in the diagram indicate the relationship between

system size S to detect reflected signals from the LAGOS and

the GS-1 at an output of rate of one photoelectron per second,

and beam divergence θt.

System size S of the transportable SLRS is designed to be

3.5 to 17 w.sq.cm, which means that the detection of one photo-

electron output per second can be obtained (detectable) by

shooting at the LAGEOS with beam divergence of approximately

100 arc seconds.

The HTLRS is expected to be operated with beam divergence

of 40 arc seconds. Then, the theoretical value of the signal

level received from the LAGEOS will be 10 to 1 p.e. per shot.

The system is designed to operate during the period of night to

twilight time.

Figure 10 shows the calculated results of the detection

probability of a few receiving systems based on the authors'

studies on weak pulse light detection[10],[11],[12]. The hori-

zontal axis in the diagram shows the noise level per gate 10

microsec., while the vertical axis shows the detection probability. Parameter Ns indicates the average number of received photons. The curves of detection probability are, from left to right, the results of threshold detection at single p.e. level, multichannel (8 channel) detection, and coincidence detection using double pulses by two output branching, respectively.

One-channel threshold detection (single p.e. detection) will be conducted in the early days of the transportable system introduction, although the multichannel or coincidence system is more desirable for twilight operation. Possibility of day time ranging may be discussed by narrowing range gate from 10 μs to 100 ns and the bandwidth of interference filter from 8 A to 1 A.

The HTLRS will employ the Nd-YAG laser. Its output is 50 mJ per pulse, pulse width is up to 200 ps, and repetition is 10 pps.

Hitachi's personal computer, Model B16/FX will be used to control the system and process data.

The Rb frequency standard with a time calibration by Loran will be employed for the timing subsystem.

The detector will be used for the micro channel PMT with gate, similarly to the Simosato system.

The optics/mount subsystem will be of a new configuration. Figure 11 illustrates a rough sketch of the optics/mount subsystem, while Fig. 12 shows its configuration. The receiving telescope is arranged so that the light axis will coincide with the elevation axis, and will be stationary for the elevation axis. The transmitting laser beam passes along the azimuth

axis, and is shot via the reflector mirror on the rear of the secondary mirror of the receiving telescope and the tracking mirror. Only the tracking mirror, installed at an angle of 45° to the elevation axis, revolves around the elevation axis. This arrangement has such advantages as that the receiving telescope can be stabilized because it is used in a nearly stationary state, that the load can be reduced because the elevation axis needs to drive only the tracking mirror, and that the transmitting optics can be simplified.

The two axes, elevation and azimuth, are driven by a direct drive torque motor.

The HTLRS is provided with an additional for detecting the flash light of the sun reflected by the AJISAI (star of magnitude 2 to 4, 2 pps, 5 ms width) and determining the flash times (rise and fall) besides the main feature for tracking and ranging the satellite. This additional feature is used to fix the time of photographic observation of the AJISAI with fixed stars in the background.

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Table 1 Major Specifications of the SLRS at Simosato

Subsystem	Specification
Mount	
Configuration	elevation over azimuth
Transmitter system	laser stationary — two axes Coudé path
Tracking rate	from sidereal to $1°$ per second
Orthogonality	±5 arcsec
Wobble	±2 arcsec in elevation, ±5 arcsec in azimuth
Angular resolution	20 bits (1.2 arcsec)
Drive	DC direct drive torque motors
Transmitting optics	
Type	Galilean
Diameter	17 cm
Beam divergence	25 μrad — 2 mrad (computer controlled)
Start pulse detector	common with receiver electronics connected by fiber optics
Receiving optics	
Type	Cassegrain
Diameter	60 cm
Field of view	100 μrad — 2 mrad (computer controlled)
Sun shutter	automatic
Spectral filter	0.8 nm bandpass (temperature controlled)
Optical attenuator	0 — 40 dB (computer controlled)
Laser	
Type	Nd:YAG
Wave length	532 nm
Output energy	150 mJ (normal)
Pulse width	200 ps
Repetition rate	1 — 4 pps (4 pps normal)
Receiving electronics	
Detector type	PMT (static crossed-field)
Quantum effeciency	29 %
Rise time	120 ps
Gate position	2 μs — 130 ms (computer controlled)
Gate width	0.2 μs — 33 ms (computer controlled)
Flight time counter	20 ps resolution
Control	
Mount control	DC servo amplifiers (45 A peak current) with torque motors, tachometers and encoders (manual, computer and computer aided)
Data flow rate	30 Hz
Clock	
Frequency standard	a Rubidium (2×10^{-11}) oscillator
Comparison	multi-Loran C waves (NW Pacific Chain)
Computer	
CPU	PDP 11/60 (64 kw Mos- and 1 kw cache memory)
Peripherals	two 5.2 Mbyte disk drives, a magnetic tape unit, a paper tape reader/punch, a hardcopy terminal and a CRT display

PROGRESS IN SLR AT SHANGHAI OBSERVATORY

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ABSTRACT

SLR work at Shanghai Observatory was started in 1975, while development of the second-generation SLR system, with the aperture of the telescope 60 cm and the width of the Nd:YAG laser pulse 4-5 nsec, was begun in 1978. During the MERIT Main Campaign the Laser Geodynamic Satellite LAGEOS has been successfully observed with this laser system. According to the CSR analyses, the accuracy of our data for single shot is about 15 cm. In that period, the system has the capability of a maximum range of about 8542 km, the lowest elevation angle of 20 degrees for LAGEOS and the longest track arc of 45 minutes in a pass.

After MERIT Campaign we began to set up a new Nd/YAG frequency-doubled mode-locked laser ranging system in order to improve the accuracy of LAGEOS ranging.

PROGRESS IN SLR AT SHANGHAI OBSERVATORY

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1. THE SLR EXPERIMENTAL SYSTEM WITH 5 CM ACCURACY AT SHANGHAI OBSERVATORY

SLR work at Shanghai Observatory was started in 1975, while development of the second-generation SLR system, with the aperture of the telescope 60 cm and the width of the Nd:YAG laser pulse 4-5 nsec, was begun in 1978. During the MERIT Main Campaign the Laser Geodynamic Satellite LAGEOS has been successfully observed with this laser system. According to the CSR analyses, the accuracy of our data for single shot is about 15 cm. In that period, the system has the capability of a maximum range of about 8542 km, the lowest elevation angle of 20 degrees for LAGEOS, and the longest track arc of 45 minutes in a pass.

After MERIT Campaign we began to set up a new Nd:YAG frequency-doubled mode-locked laser ranging system in order to improve the accuracy of LAGEOS ranging. This system consists of an oscillator, a pulse selector, two amplifiers and a frequency-doubler. The oscillator mode-locked by using both acousto-optic modulator and saturable dye produces a sequential laser pulse trains.

The width of each pulse with TEM00 mode is 32 picoseconds. The pulse selector extracts one single pulse out of the pulse train, then is amplified through the two amplifiers. The output energy from the amplifiers is about 100 mj per pulse at 1.06 μm. In order to match the pulse width with the rise time of receiving system, the pulse width are expanded to 120 ps by using two F-P mirrors. After frequency doubled with a KDP crystal, the output energy is now 30-50 mj at 0.53 μm. The block diagram of Nd:YAG mode-locked laser system is shown in Fig. 1. The width of output pulse has been measured with a streak camera, it is shown in Fig. 2.

A 8-bit microcomputer with 64k byte memory is used for real-time tracking control which is made in China. The accuracies of both predicting and tracking are about 10 arcseconds.

In Nov. 1985, the mode-locked laser system was set up at Zo-Se Station of the Shanghai Observatory. On Dec. 12, 1985, we received the first echo from LAGEOS by the new laser system. Five passes with 606 data were obtained

during the experimental stage. These data had been preprocessed with a residual analytic program of our Observatory. The result is shown in Table 1 and Fig. 3-6. Meanwhile we transmitted these quick-lock data to NASA/GLTN. The GLTN and CSR have analyzed these data, Table 2 lists their results.

From Table 1, 2, we can see that the accuracy of this new SLR system is about 5 cm for single shot.

In order to explore the stability of the experimental system, a ground target set on the top of a water tower separated by 675.6 meters away from the laser, is used for calibration of the laser system. apertures of different size representing different return signal strength have been used on both receiving and transmitting telescopes to simulate the return signal strength from the satellite. The results of the calibration for ground target indicate that the stability of mode-locked ranging system is about 0.11 ns (2 cm). See Table. 3.

It is expected that the third-generation SLR system at Shanghai Observatory will be in routine operation from Sept. 1986 onwards.

2. SLR DATA ANALYSIS

During the MERIT Main Campaign, as one of the Associated Analysis Center, the Shanghai Observatory had processed the global data of LAGEOS satellite, using the software named SHORDE, which stands for Shanghai Observatory Orbit Determination Processor. The results obtained are A series of ERP-ERP (SHA) 85L01. It lists the solutions for two components of polar motion for each 5-day arc since the beginning of Sept. 1983. The interval precision is approximately 2.1 mas for x_p, 2.2 mas for y_p and 0.13 ms for D_R. In addition, the ability to detect the rate of change of polar motion $\dot{x}_p$ and $\dot{y}_p$, with 5-day arc solution has been estimated to be approximately 1 mas/day.

The accuracy of the determination of the orbit of LAGEOS satellite is about 14 cm for each 5-day arc from the overall weighted RMS fit of the laser observations to the orbits.

Using SHORDE software, we determined the length of the baseline between two Chinese SLR stations of Shanghai Observatory and Xian Institute of Geodesy and Cartography. All observational data are divided into two arcs: 5-day arc from 18 through 22, Oct. 1984 and 4-day arc during 23-26, Oct. 1984. They are processed respectively. The weighted mean value of two solutions is equal to 1192562.89±0.11 m. The obtained result can be for checking the length survey of geodetic triangulated network. The researching work of the determination of global plate motion and deformation using LAGEOS tracking data is also underway.

Recently we have also completed a program for the transfer of the full-rate data to normal point data. This program includes: (1) pre-processing of full-rate data, (2) generating short-arc/long-arc trajectories for LAGEOS and removing some of the effects of the unmodeled perturbations, and (3 obtaining normal point data and identifying bad observations.

3. THE CHINESE SLR NETWORK

The Chinese SLR network is also being developed. At present, his e w r consist of seven stations located at Shanghai. Wuhan, Xianhn, unmin ,

Xian, Guangzhou, and Zhengzhou. The ranging accuracy of these stations, except the Shanghai and Wuhan Stations, is about 2 cm for single sho. By 1988, two SLR systems of the third generation will be joined int the network. The Chinese SLR network is aimed at geodesy, astronomy and ge- dynamcis applications such as building of the zero order geodetic controlling network, monitoring of the regional crustal deformation and so on.
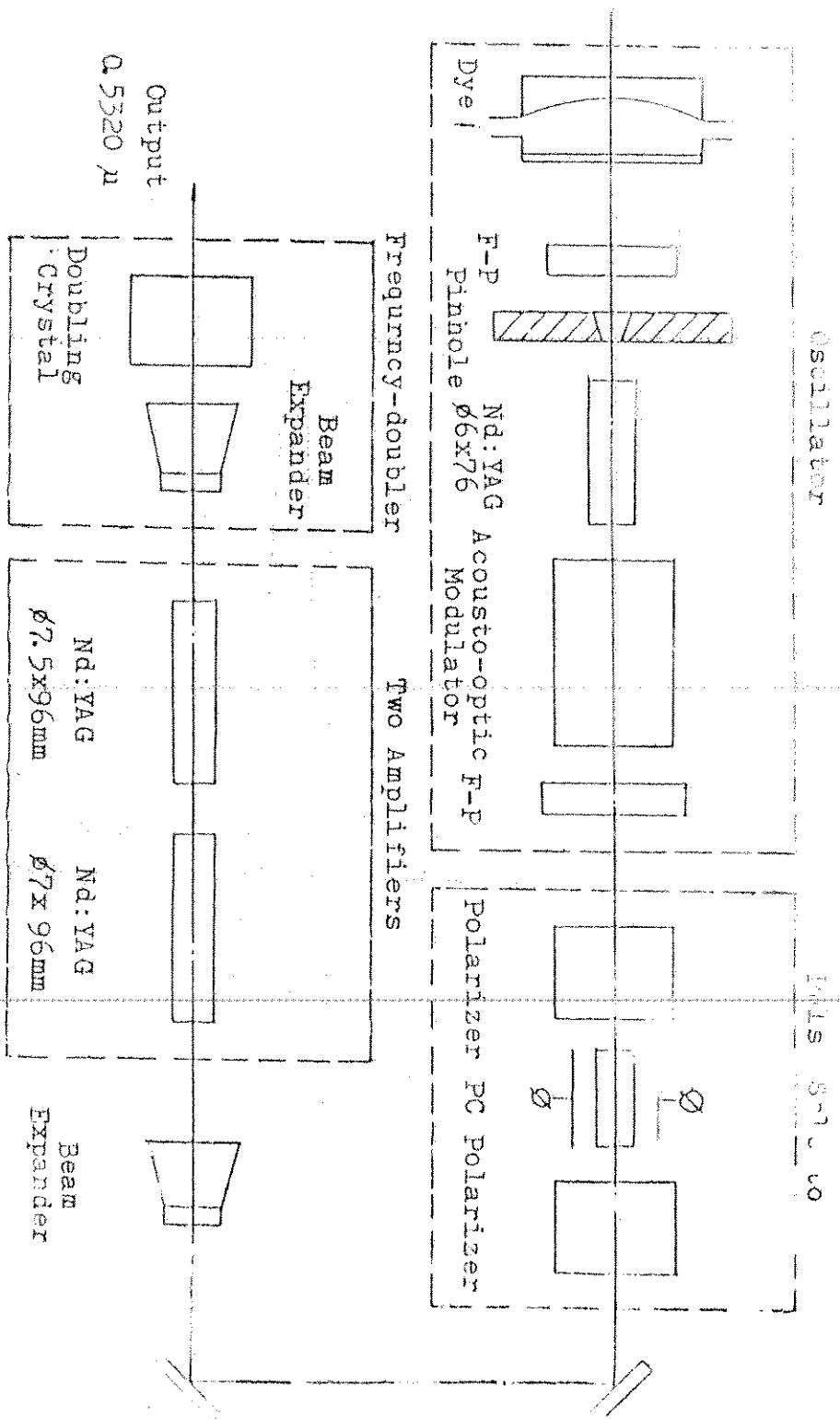
Oscillator

Dye

F-P Pinhole ⌀6x76

Nd:YAG Acousto-optic F-P Modulator

Polarizer PC Polarizer

Frequency-doubler

Doubling Crystal

Beam Expander

Two Amplifiers

Nd:YAG ⌀7.5x96mm

Nd:YAG ⌀7x96mm

Beam Expander

Output 0.5320 μ

Fig.1 The Block Diagram of Nd:YAG Frequency-Doubled Mode-Locked Laser System
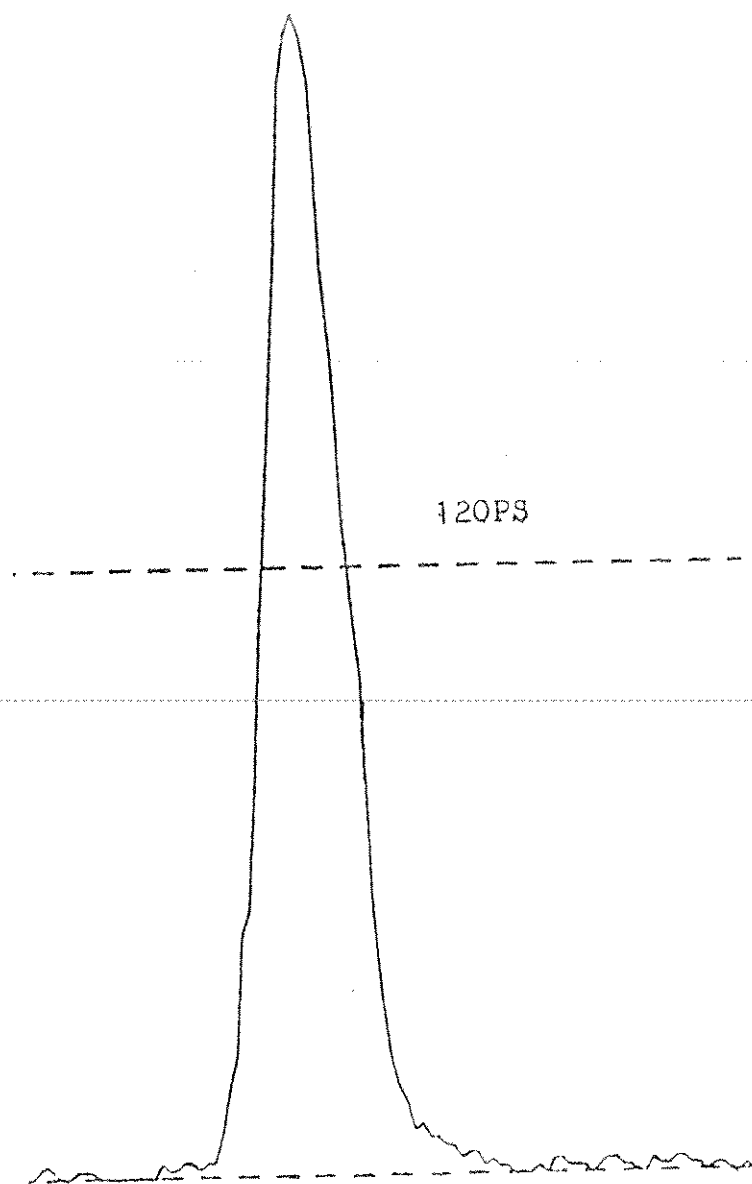
120PS

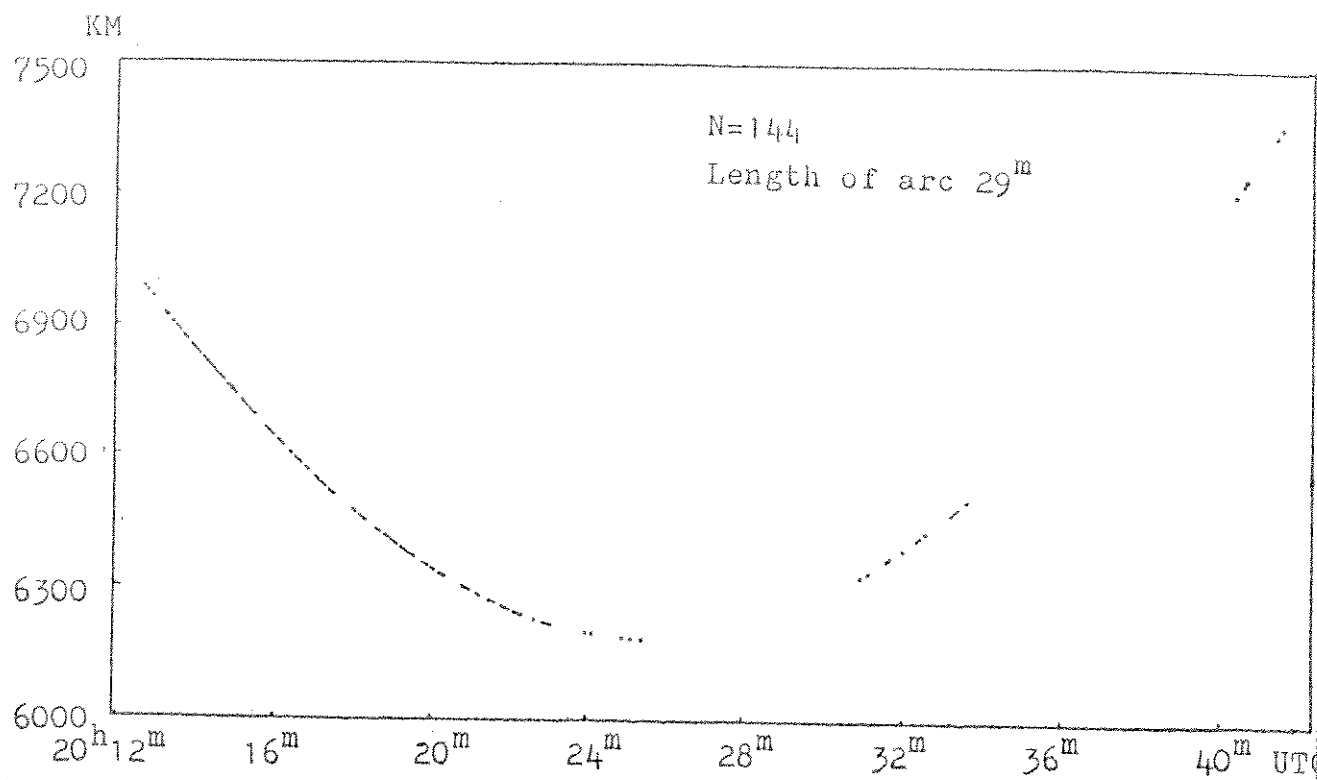Fig.2 Pulse Width Measured with Streak Camera .

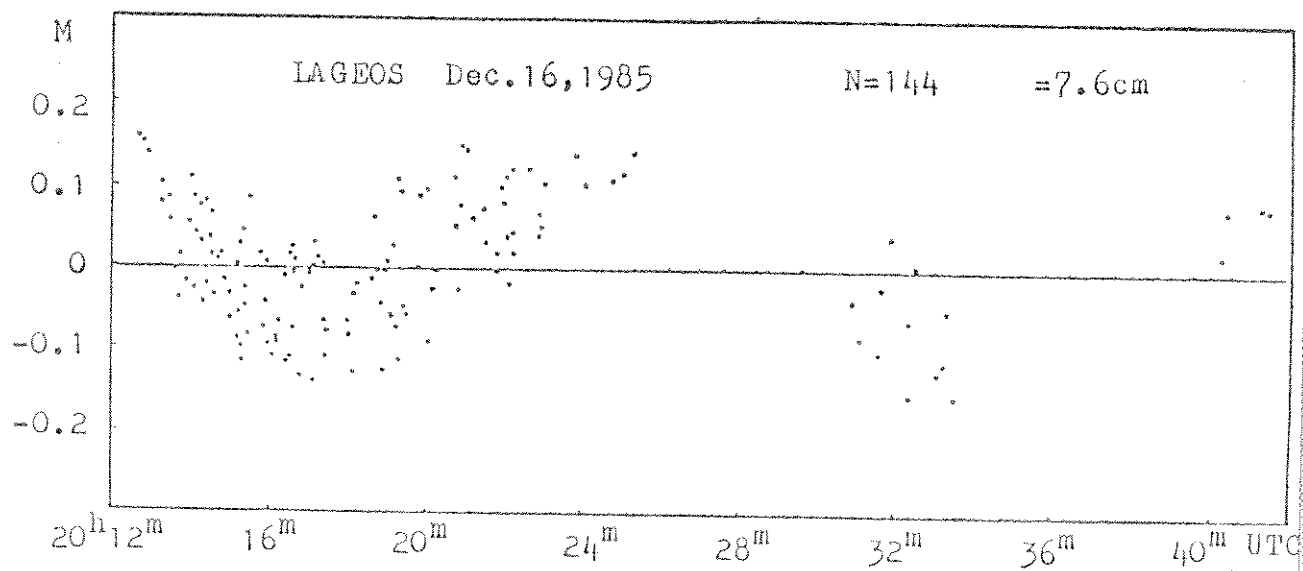Fig.3   The Observing values for LAGEOS (Dec.16,1985)
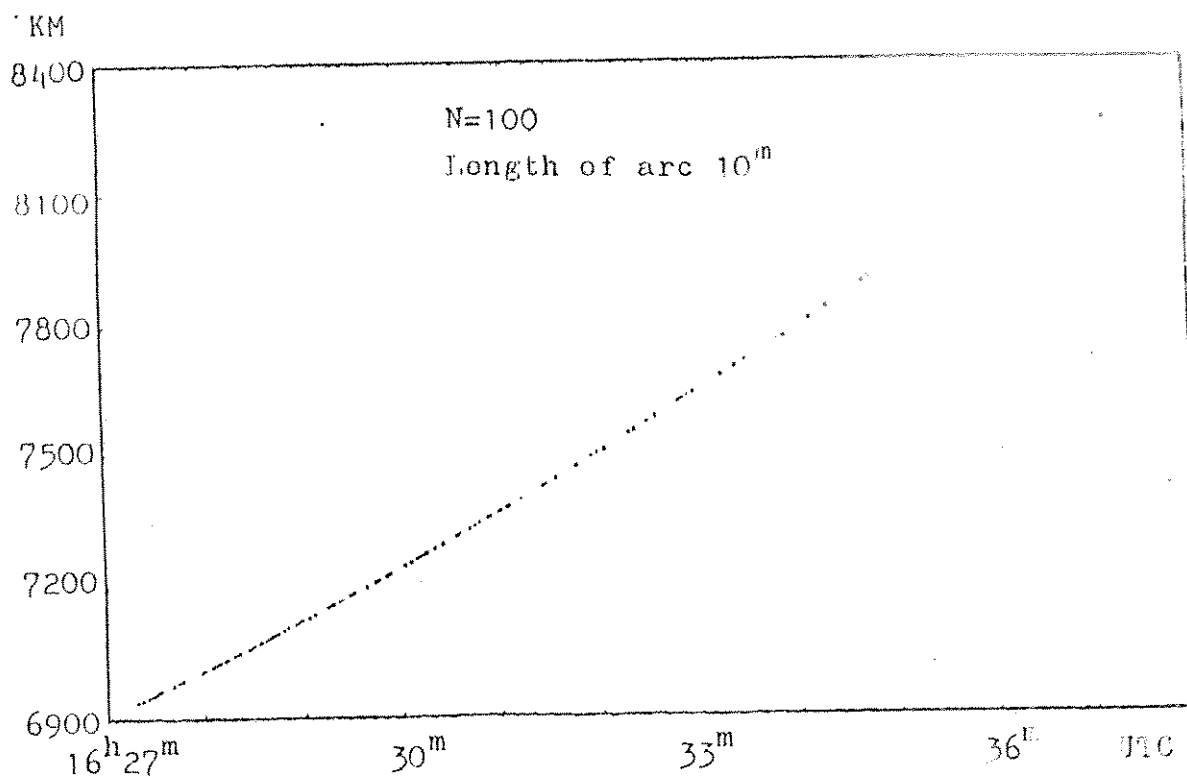

Fig.4   The residuals after polynomial fitting
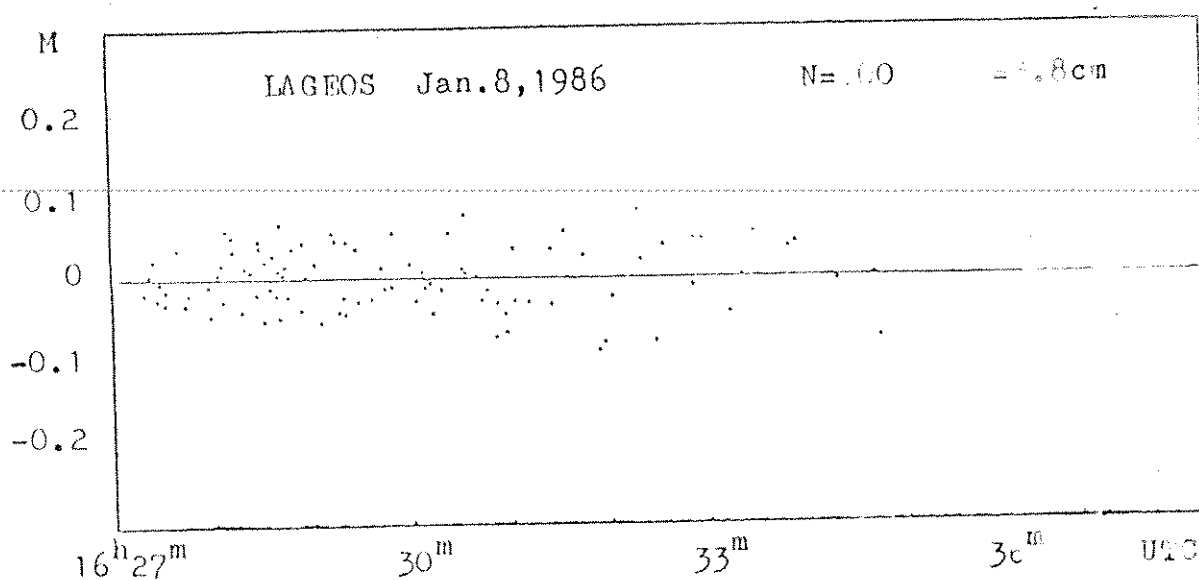
Fig.5   The Observing values for LAGEOS Jan 8,1986

Fig.6   The residuals after polynomial fitting

Table 1 The Summary of Observation for LAGEOS with Mode-Locked Laser

Date	Time	Length of arc	Total Obs.	Accuracy (cm)
Dec.12,1985	18^h48^m--18^h59^m	11^m	182	6.3
Dec.16,1985	20^h12^m--20^h41^m	29^m	144	7.6
Jan. 5,1986	17^h43^m--17^h56^m	13^m	133	6.1
Jan. 8,1986	17^h21^m--17^h37^m	10^m	131	6.9
Jan. 9,1986	19^h16^m--19^h23^m	7^m	16	5.0

Table 2   The Results of Analysis at GLTN and CSR

Date	No. of the Obs. Sent	GLTN		CSR	
		Good Obs.	Accuracy (cm)	Good Obs.	Accuracy (cm)
Dec.12,1985	80	61	7.2	75	6.4
Dec.16,1985	50	49	4.9	49	5.9
Jan. 5,1986	100	97	4.5	97	4.4
Jan. 8,1986	100	100	3.5	100	3.8
Jan. 9,1986	15	14	6.0	14	5.2

Table 3   Calibrated Stability for Ground Target (Dec.16,1985)

Transmitter Aperture(cm)	Receiver Aperture(mm)	No. of Measure	Value of Obs.(ns)
1 x 4	2	51	4650.19
1 x 4	8	54	4650.15
1 x 4	2	97	4650.09
0.5 x 4	2	53	4649.97
1 x 4	2	69	4649.91
0.3 x 4	1	11	4650.16
Average			4650.08 ± 0.11
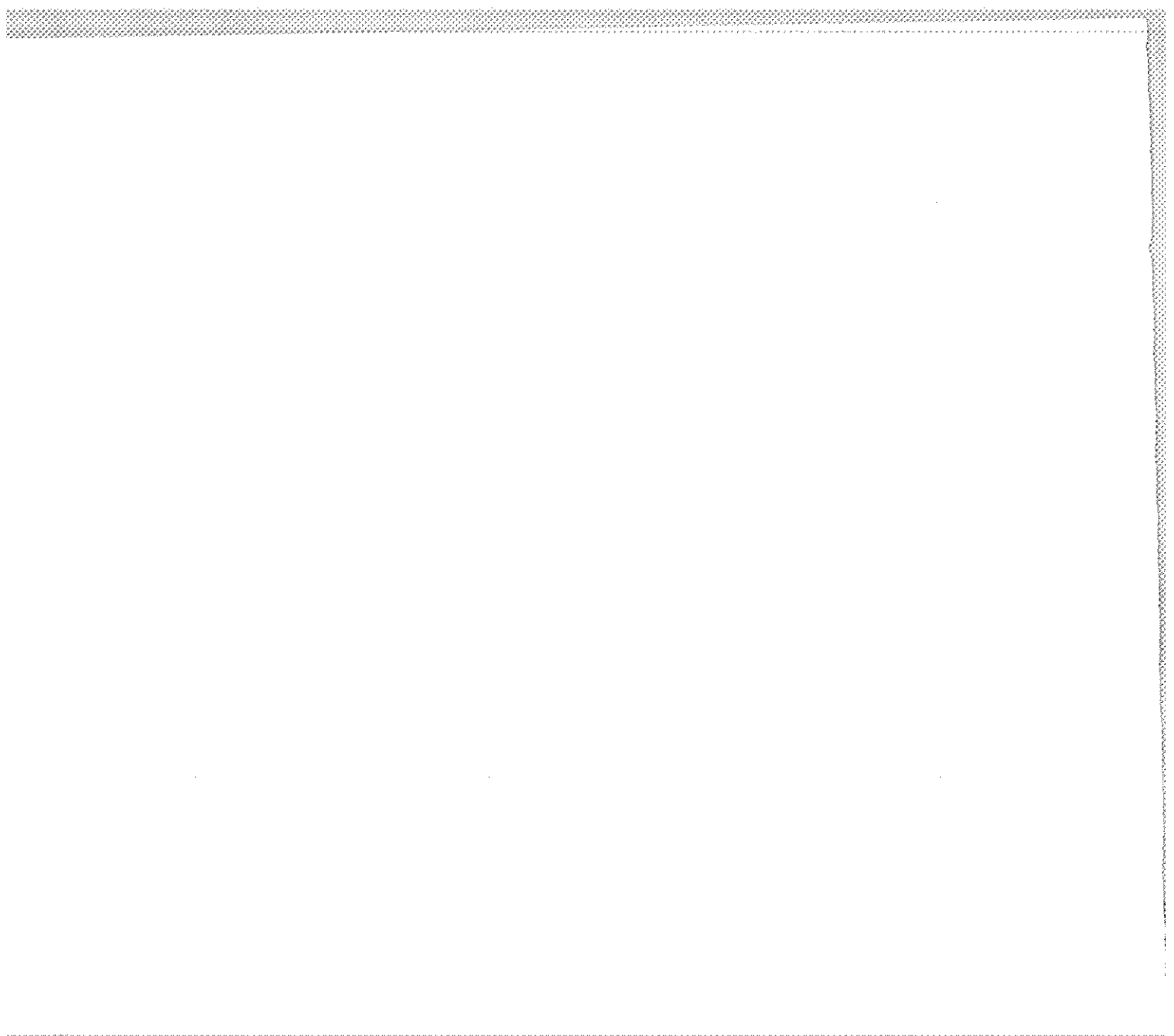
INTERKOSMOS LASER RADAR, VERSION MODE LOCKED TRAIN

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ABSTRACT

The INTERKOSMOS 2.generation satellite laser station, built in 1980, located in Helwan, has been operating since 1982 in the mode locked train version. To improve the performance several upgradings have been made since 1984. To improve RMS, the new Start detector and HP5370B counter have been implemented. To improve the reliability the transmitter has been placed into the Coude. To study new detectors, the independent receiver chain No.2, consisting of Newtonian 32 cm telescope, detector and HP5360 counter has been implemented. This arrangement allows to apply different detectors including solid state silicon diode operating at room temperature on single/multi photon signal level.

INTERKOSMOS LASER RADAR, EMISSION MODE-LOCKED TRAIN

K.Hamal,M,Čech,H.Jelínková,A.Novotný,I.Procházka
B.B.Baghos,M.Tawadros,Y.Helali

The INTERKOSMOS 2.generation laser radar, built in 1980 [1] located in Helwan, has been operating since 1982 in mode-locked train version [2]. To improve the performance several upgradings have been made since 1984.

To improve RMS, the new Start detector and HP5370B counter have been implemented. The Start Detector [3], using a transistor, contributed 50 psec to the RMS budget. The detector chain Nr.1 consists of PMT RCA31034A, two HP8447 amplifiers, ORTEC 473A discriminator and HP5370B counter.

To improve the reliability, the transmitter has been placed into Coude focus. A tremendous increase of the laser output stability was resulted. The laser transmitter itself was examined to identify the optical elements influencing the beam quality [4]. The saturable dye was tested under different conditions [5].

To study new detectors [6], the independent receiver chain Nr.2, consisting of the Newtonian 32cm telescope, detector and HP5360 counter has been implemented. This arrangement allows to apply different detectors (solid state diode [6]), while routine ranging has been provided using the original receiver chain Nr.1. To have a comparision, the MCP PMT Varian has been tested at the indoor calibration facilities [7].

To collect data from both chains, the computer software package has been modified. To simplify the calibration, ranging and data processing procedures, some other modifications have been implemented into the software package.

The calibration and system stability tests have been acomodated to the upgraded version [10].

The strong signal response from the photodiode was measured at the indoor calibration facilities [9].

Summary.

	before upgrading 1984	after upgraging 1986		
		PMT	MCP-PMT	diode
System stability (ps)	150	110		25
System jitter (ps)	520	300	100	100

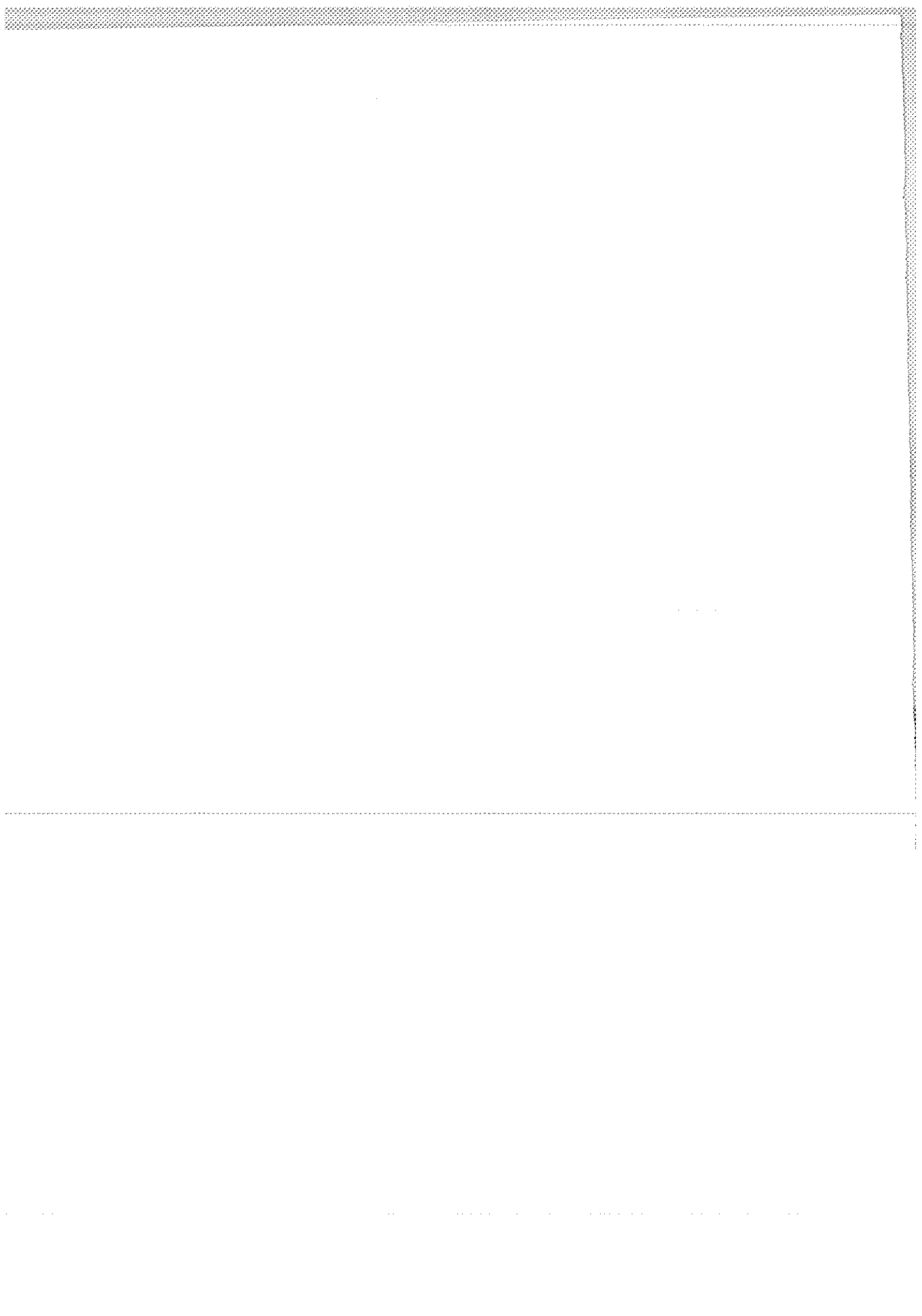Upgrading of the existing 2.generation laser station into 3.generation has been proposed [10].

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    INTERKOSMOS LASER RADAR, VERSION MODE LOCKED TRAIN
    Proceedings of The Fifth International Workshop, Greenwich, 984
In this Proceedings:
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    START DETECTOR FOR MODE LOCKED TRAIN LASER RADAR
[4] H.Jelinkova,J.del Pino,P.Valach
    SPATIAL STRUCTURE OF THE DOUBLED ND:YAG LASER TRANSMITTER BE M
[5] K.Hamal,H.Jelinkova, STABLE SATURABLE DYE FOR 1.06UM
[6] K.Hamal,H.Jelinkova,I.Prochazka,B.Sopko, SINGLE PHOTON
    SOLID STATE DETECTOR FOR RANGING AT ROOM TEMPERATURE
[7] I.Prochazka,K.Hamal,J.Gaignebet, MICROCHANNEL/DYNODE PMT
    COMPARISON EXPERIMENT
[8] K.Hamal,I.Prochazka, SYSTEM STABILITY USING MODE LOCKED TRAIN
[9] I.Prochazka,K.Hamal,H.Jelinkova, PICOSECOND LASER RANGING
    USING PHOTODIODE
[10] K.Hamal,I.Prochazka, 3.GENERATION/VERSION MODE LOCKED TRAIN

RECEIVER Nr.1   RECEIVER Nr.2
REFRACTOR   NEWTON

LASER OUT

LASER IN
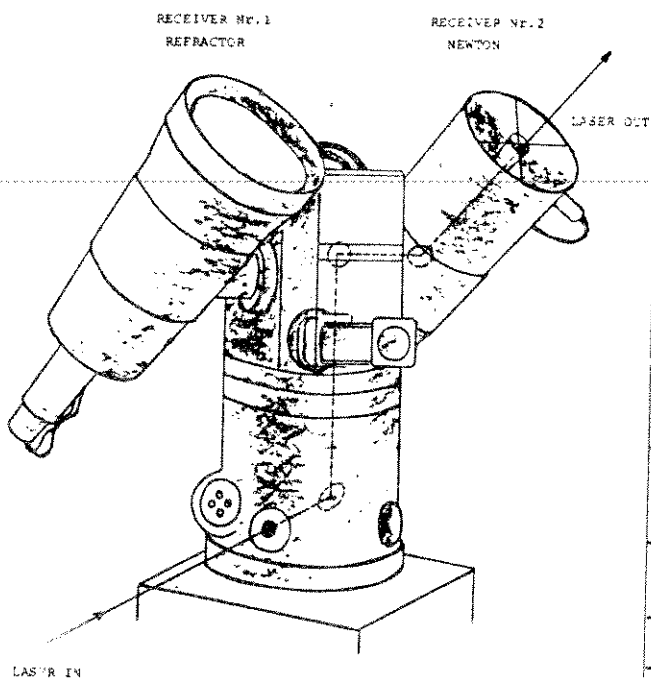
View of the mount. Refractor receiver Newton receive.

2.Generation Mode Locked Train, Helwan 1986				
UPGRADINGS 1985 - 1986				
RMS	START DETECTOR <50ps COUNTER HP5370B			
LASER RELIABILITY	LASER SYSTEM	COUDE BEAM STRUCTURE SATURABLE DYE		
EXPERIMENTAL RECEIVER Nr.2	NEWTONIAN 32CM			
SOLID STATE DETECTOR	SINGLE MULTI	PHOTON DETECTION		
SOFTWARE PACKAGE	MODIFICATION TO SIMLIFY CALIBRATION RANGING, DATA PROCESSING PROCEDURE			
	1984	1986		
	PMT	PMT	MCP PMT	DIODE
SYSTEM STABILITY ps	150	110		25
SYSTEM JITTER ps	520	300	100	100

K.Hamal,M.Cech,H.Jelinkova,A.Novotny,I.Prochazka
Interkosmos Laser Radar,Version Mode Locked Train   1

UPGRADES AND NEW DEVELOPMENTS
ON SATELLITE LASER RANGING
STATION FROM GRASSE

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Telex 470865 F

ABSTRACT

The Grasse Satellite Laser Station, operating since 1978, in a first step with a decimeter accuracy has successively been upgraded.

At first the ruby laser was replaced by an active mode locked Nd:YAG laser in 1984 and it puts the system at a centimeter level.

After that, in view to give to this station a total efficiency and autonomy the replacement of the computer was undertaken and this improvment should be ready before the end of 1986.

This paper describes the station today (hardware and software), its performances and its possibilities.

1. OVERVIEW OF THE SATELLITE LASER RANGING FROM GRASSE

===

The Satellite Laser Ranging of GRASSE is, in fact, installed in the mountains just above Grasse where the astronomical Observatory of the CERGA has been built. (Annexe 1)

The site is a plateau at a 1250 meter altitude at 20 Kilometers from Grasse and the weather is particularly favorable to Laser Ranging.

This S.L.R. Station developed in the Years 75-78 and entirely financed by the French Spatial Organisation (C.N.E.S.) obtained the first returns in 1978 and, since this time, in spite of some interruptions, it has provided to the Scientific community a lot of data of an increasing quality.

In order to minimize the interruptions of data, the modi--fications and upgrade have been carried out in stages.

In a first time the Ruby Laser System (3 Nanosecondes of PWHM) was replaced by an active Mode-locked ND:YAG in 1984 and in a second time (1985) the change of the computer and software was undertaken.

For this occasion, the software was totally refurbished in taking into account the new techonology and the requirements for the data (great number of data, need of quick dispatching the results with the new link possibilities, ...)

This very important work is beeing terminated in a few weeks and so, the station will acquire all the possibilities of a modern station.

2.HARDWARE EQUIPMENTS
==================

Except the Mount,the Telescope and the computer,all the hardware equipments are installed in a schelter,where the operators stand during the ranging,close to the building.

The mount rests on a concrete pier at 3 meters from the ground and a floor independant from the mount allows to reach the equipment attached to the telescope.

2.1 MOUNT,TELESCOPE(Annexe 2)

The optical system consists of:

- The Telescope(Cassegrain)proper of a diameter of 1 meter and a focal length of 8 meters;it is especially dedicated receiving light from returns.

- The transmitting afocal optics made of lenses with a diameter of 20 Centimeters.

-A sighting Refracting Telescope to achieve some adjustments(particularly the alignment of the transmitting and receiving axes,the firing direction,and to observe the satellites when they are illuminated.

As the Telescope,the Mount was designed,drawn and built in FRANCE,it is an altazimuth system with an absolute accuracy of about 10 arcseconds.

The encoders(absolute)have a resolution of 1.2 arcseconds (2 bits).

The laser beam is going to the transmitting optic through a coude path with five coated mirrors.

2.2 ND:YAG LASER(Annexe 3)

_____

This transmiter built by QUANTEL FRANCE currently
provides a single 200 Picoseconde pulse at a repetition rate
of 5 Hertz or 10 Hertz.

One of the distinctive features of this system is that
it is possible to operate the oscillator either in passive
(with dye) or in active(with pockel cells) mode;this active
mode is generally used for an easier operating.
An active mode-locker(at 70 Megahertz)in the cavity
increase the stability of the pulse train.

At the outgoing of the oscillator,the slicer(with
avalanches transistors)selects one pulse and,after a double
pass and the final amplifier,the single pulse energy is
currently 100 Millijoules per shot in the green.

2.3 TIMING EQUIPMENTS.(Annexe 4)

_____

The chronometry is achieved by a Thomson event-timer
of for channels(1 start and 3 stop).The resolution of this
equipment is of 100 Picosecondes.

The start time is trigerred by a photodiode on the
Laser bench and through a TENNELEC discriminator.

The Photomultiplier tube(RTC 2233b)is going replaced
in a few time by a Micro channel plate HAMAMATSU PMT in view
to increase the RMS of the data and reduce systematic biases.
A constant fraction discriminator TENNELEC is used for the
stop channels.

With such a configuration,the RMS currently
achieved is from 3 to 5 Centimeters on a satellite pass.

2.4 COMPUTER:

The Computer is a DIGITAL EQUIPMENT(DEC) PDP 11-73 with a memory size of one Mega-byte and an optional hardware to increase the speed of floating operations.

- Numerous specialized interfaces to control the Servo of mount, the encoders,the event-timer,electronic systems to elaborate the range gate,..

* 3 parallel I/O 64 bits

* 1 Real-time clock

* 1 Digital/Analog converter

-A Track-ball(connected by an asynchronous link)in view:

* To introduce corrections during the tracking

* To process the data

Different mass storages are connected to this computer:

- Two removable disk systems of 10 Mega-bytes

* One for the system.

* One for the software developments.

- One Winchester disk of 160 Mega-bytes

*Storage and editing the data.

ne Magnetic Tape drive(one-half inch,1600 BPI)

* Disk backups

* Editing full rate data

* Different exchanges

This computer is connected(by the VAX in grasse) to the
computing center of CNES in TOULOUSE.

3.SOFTWARE
==========

The computer is running under the Real-time Multitask,
Multiusers RSX 11 M PLUS Operating System.

According to their functions,all the modules were written
either in Assembly language(Driver modules,Process control,
Interrupt services routine modules,...) or in Fortran 77
Language for all the scientific calculations and every time it
was possible.

The programs are accessible to the operators through
a system of Menu .

The different possibilities are:

-Computing the shedules of a given satellite.

-Tracking:
            * Stars.
            * Satellite(Ranging)
            *Target(Calibration)

- Preprocessing Data
    * Manual
    * Automatic

- Editing
    *Quick-Look
    *Full rate Data

3.1 SCHEDULE COMPUTING(Annexe 5)

Once a Month the Operator computes the Schedule of
LAGEOS,STARLETTE and AJISAI(Rise time,Set time ,Max Elevation)
in view to establish work schedule for the crew.

These computations are achieved with the IRV for LAGEOS
and Keplerian Elements for other satellites.

3.2 TRACKING(Annexe 6 et 7)

The capability to track the stars(direct and reverse)
is needed to adjust the encoders and the parameters of the
mount.

The tasks which control the tracking of a satellite
are numerous.

-Preliminary computation of Site,Azimuth and range
of the satellite every second of time.

In real time:

Interpolating position(50 Hertz)

* Servo control of the mount(activation every 20 Milliseconds
  by internal clock)
      Reading Encoders
      Reading Track-Ball for correction
      elaborating speed orders for servo amplifier site and
      azimuth

* Interpolating range and derived of range

* Loading Range Gate(Activation by an interrupt on firing,5 Hertz)

* Reading Start an Stop time on the event timer(Interrupt on
  the end of gate)

* Computing of residuals for the exact firing time(With
predicted range and his derived)for later processing and
recording on a file.

* Ploting on Graphic display residuals and informations for
operator.

* Reading operator commands.

3.3 TARGET CALIBRATION(Annexe 8)

After each pass,a calibration is achieved on a ground
target erected at a distance of about 2.5 Kilometers.

Five hundred returns are recorded and processed.

The calibration is appended to the file of the
preceding pass with the meteorological data.

3.4 PREPROCESSING DATA

The preprocessing of the data is entirely based on the residuals computed during the pass.

To avoid to spend a lot of time to read files and to give more flexibility to the software,all the data are loaded in the memory of the computer at the beginning with managment memory facilities.

The data residuals are plotted on the graphic screen and the operator can execute with the Track-ball a manual cleaning (Annexe 9)of the data,after what an automatic algorithm(with polynomial fitting,elimination at 2.5 RMS and iteration) terminates the processing.(Annexe 10).

3.5 EDITING QUICK LOOK AND FULL RATE DATA:

After the cleaning of the data,the operator can edit quick-look of the pass and send it to CNES in TOULOUSE where an automatic telex will send it twice a week to the users.

The full rate data are computed and stored on the Winchester disk and on a magnetic tape.

The original file(not processed)is copied on a tape to be preserved.

PLATEAU DE CALERN

C.E.R.G.A.

ANDON

GREOLIERES

DIGNE

CAUSSOLS

GOURDON

St VALLIER DE THIEY

NICE

PRE DU LAC

GRASSE

DRAGUIGNAN

ANTIBES

CANNES

SATELLITE GEODESIQUE

DIAMETRE 1m
DE RECEPTION

OCAL D'EMISSION

MIROIRS DE
RENVOI

OBJECTIF DE VISEE

CODEUR SITE

CAMERA TV

PHOTOMULTIPLI-
CATEUR 100 ps

FAISCEAU LASER

LASER

100 ps

générateur
d'harmoniques

amplificateur
final

amplificateur
double passage

sélecteur
d'impulsions

OSCILLATEUR LASER

SATELLITE GEODESIQUE

PDP 11-73

DISTANCE PREDITE

DATEUR D'EVENEMENTS

100 ps

1 VOIE

TIR

3 VOIES

EVENEMENTS

~100 ps

PHOTO-DIODE

BANC LASER

discriminateur à fraction constante 90 ps

PORTE

100 ps

FAISCEAU LASER

OBJECTIF DE VISEE

CODEUR SITE

CAMERA TV

PHOTOMULTIPLI-CATEUR 100 ps

DIAMETRE 1m DE RECEPTION

AFOCAL D'EMISSION

MIROIRS DE RENVOI

EGS DEBUT: MERCREDI 17 SEPTEMBRE 86

         FIN: LUNDI   6 OCTOBRE   86

MERCREDI	17 SEPTEMBRE 86	10H 4MN	21	-	164	116	77	+	390451	524031	643049
MERCREDI	17 SEPTEMBRE 86	12H 1MN	68	-	223	106	62	+	218467	560735	689738
MERCREDI	17 SEPTEMBRE 86	14H 3MN	65	+	264	15	69	-	100085	824278	668200
MERCREDI	17 SEPTEMBRE 86	16H 0MN	62	+	290	40	93	-	23830	751231	597080
MERCREDI	17 SEPTEMBRE 86	18H 9MN	74	-	296	175	131	+	5333	357961	487389
MERCREDI	17 SEPTEMBRE 86	20H 11MN	25	-	284	223	183	+	41960	217866	336681
JEUDI	18 SEPTEMBRE 86	9H 13MN	12	-	139	112	92	+	463852	542936	599109
JEUDI	18 SEPTEMBRE 86	11H 8MN	50	-	207	119	64	+	264725	522064	681340
JEUDI	18 SEPTEMBRE 86	13H 9MN	74	+	253	29	64	-	132543	783577	681815
JEUDI	18 SEPTEMBRE 86	15H 12MN	59	+	284	37	83	-	39791	760764	626813
JEUDI	18 SEPTEMBRE 86	17H 14MN	86	+	297	105	118	-	4402	563092	524984
JEUDI	18 SEPTEMBRE 86	19H 17MN	37	-	288	220	153	+	28191	228312	392781
VENDREDI	19 SEPTEMBRE 86	10H 15MN	35	-	190	123	67	+	313778	509720	672568
VENDREDI	19 SEPTEMBRE 86	12H 19MN	83	+	240	53	62	-	169944	697595	687014
VENDREDI	19 SEPTEMBRE 86	14H 18MN	59	+	277	17	76	-	60790	819111	647626
VENDREDI	19 SEPTEMBRE 86	16H 20MN	73	+	295	63	106	-	9684	685685	559558
VENDREDI	19 SEPTEMBRE 86	18H 22MN	52	-	295	196	148	+	10216	298154	438019
VENDREDI	19 SEPTEMBRE 86	20H 27MN	13	-	266	232	212	+	94406	193534	250312
SAMEDI	20 SEPTEMBRE 86	9H 23MN	2								

LACEDE DEBUT: JEUDI   18 SEPTEMBRE 86

         FIN: LUNDI   3 NOVEMBRE 86

JEUDI	18 SEPTEMBRE 86	4H 1MN	68	+	27	119	197	-	790217	521346	234565
JEUDI	18 SEPTEMBRE 86	7H 34MN	51	-	35	327	263	+	766194	963706	102786
JEUDI	18 SEPTEMBRE 86	10H 57MN	43	-	77	12	315	+	643355	834055	999516
JEUDI	18 SEPTEMBRE 86	14H 20MN	89	-	142	329	333	+	454154	957670	948353
JEUDI	18 SEPTEMBRE 86	18H 7MN	23	+	222	273	322	-	221659	73941	978419
VENDREDI	19 SEPTEMBRE 86	2H 38MN	42	+	29	104	170	-	784489	566399	372638
VENDREDI	19 SEPTEMBRE 86	6H 12MN	68	-	29	309	238	+	783501	1016040	174470
VENDREDI	19 SEPTEMBRE 86	9H 40MN	40	-	57	354	300	+	703682	886658	1044249
VENDREDI	19 SEPTEMBRE 86	13H 0MN	66	-	117	32	329	+	526756	775857	958746
VENDREDI	19 SEPTEMBRE 86	16H 34MN	45	+	186	260	332	-	327508	110665	950227
SAMEDI	20 SEPTEMBRE 86	1H 20MN	20	+	41	89	134	-	748108	608071	477919
SAMEDI	20 SEPTEMBRE 86	4H 49MN	87	+	27	176	214	-	791088	356202	245577
SAMEDI	20 SEPTEMBRE 86	8H 21MN	44	-	42	339	278	+	746615	930361	57418
SAMEDI	20 SEPTEMBRE 86	11H 42MN	49	-	93	22	322	+	598605	805373	978554
SAMEDI	20 SEPTEMBRE 86	15H 9MN	71	+	159	251	333	-	404351	136027	947105
SAMEDI	20 SEPTEMBRE 86	19H 14MN	10	+	269	283	296	-	84431	45465	6575
DIMANCHE	21 SEPTEMBRE 86	3H 26MN	59	+	27	116	188	-	790916	529219	312703
DIMANCHE	21 SEPTEMBRE 86	7H 0MN	55	-	33	321	255	+	772935	983279	125335
DIMANCHE	21 SEPTEMBRE 86	10H 25MN	41	-	70	7	310	+	665505	847815	1013104
DIMANCH											

STARLETTE DEBUT: MERCREDI 17 SEPTEMBRE 86

           FIN: LUNDI   6 OCTOBRE   86

MERCREDI	17 SEPTEMBRE 86	11H 34MN	16	-	160	114	86	+	401014	535892	618366
MERCREDI	17 SEPTEMBRE 86	13H 20MN	68	-	226	98	63	+	209713	581577	683986
MERCREDI	17 SEPTEMBRE 86	15H 9MN	54	+	270	32	65	-	82235	774941	678679
MERCREDI	17 SEPTEMBRE 86	16H 59MN	52	+	294	51	89	-	10776	721191	612214
MERCREDI	17 SEPTEMBRE 86	18H 46MN	82	-	296	139	123	+	5598	462472	509379
MERCREDI	17 SEPTEMBRE 86	20H 30MN	27	-	278	212	171	+	58090	251288	370234
JEUDI	18 SEPTEMBRE 86	11H 52MN	29	-	186	115	71	+	326746	533815	661335
JEUDI	18 SEPTEMBRE 86	13H 39MN	77	+	244	54	62	-	158230	709720	687697
JEUDI	18 SEPTEMBRE 86	15H 29MN	49	+	282	17	71	-	47553	813227	661568
JEUDI	18 SEPTEMBRE 86	17H 18MN	61	+	296	49	99	-	5859	726373	578706
JEUDI	18 SEPTEMBRE 86	19H 8MN	57	-	292	173	139	+	19092	365101	464923
JEUDI	18 SEPTEMBRE 86	20H 58MN	16	-	268	222	191	+	87692	221607	312149
VENDREDI	19 SEPTEMBRE 86	12H 10MN	47	-	211	114	65	+	253079	536690	678437
VENDREDI	19 SEPTEMBRE 86	13H 59MN	64	+	260	20	63	-	111358	810820	684010
VENDREDI	19 SEPTEMBRE 86	15H 49MN	49	+	291	30	79	-	20417	782230	637767
VENDREDI	19 SEPTEMBRE 86	17H 38MN	78	+	298	91	112	-	1541	603698	543222
VENDREDI	19 SEPTEMBRE 86	19H 27MN	38	-	287	201	155	+	31353	282928	417681
SAMEDI	20 SEPTEMBRE 86	10H 43MN	18	-	166	113	80	+	384576	524935	634538
SAMEDI	20 SEPTEMBRE 86	12H 29MN	69								

synchronisation, priorite, description generale

```
                                              =============        =============
                                              | DISSOR    |        | ECHO      |        | TRAISG    |
                                              |   PRI=250 |        |   PRI=250 |        |   PRI=100 |
                                              |entree:    |        |dans ITSR  |        |entree: buffer|
                                              |distance   |        |saisie de 2|        |des resultats|
                                              |remplie par|        |voies      |        |eftrait=0  |
                                              |DCHARG     |        |si simple tir|      |met dans fichier|
                                              |dans ITSR  |        |range voie1|        |- temps aller-|
                                              |sortie distance|    |(date tir) |        |  retour   |
                                              |sur perif  |        |range voie2|        |- residus  |
                                              |specialise |        |(date echo)|
                                              |si double tir|      |maj flag echo|      |attente de |
                                              |ou cible   |        |eftrait=1  |        |eftrait=1  |
                                              |.lit et range|      |(ECHO non actif|    =============
                                              |les 2 voies|        |si cible)  |
                                              |.demande heure|     |sort si effin=1|
                                              |si cible alors|     =============
                                              |eftrait=1  |
                                              |sort si effin=1|
                                              =============
```

IT de tir
IT de porte
fin de porte

                              MENU
           lance la tache de preparation appropriee

     CIBLE   ETOILE   SATELLITE   PRETRA   HORAIR

TACHE PREPSG: PREPARATION POUR POURSUITE SATELLITE GEODESIQUE
   dialogue operateur pour connaitre le nom du satellite
   prise de l'heure sur horodateur
   mise a l'heure du calculateur
   s'il existe un passage de ce satellite a cette heure,
     -> creation eventuelle du fichier de previs au pas de 1 s
     -> ouverture du fichier de previs
   initialisations en particulier frequence de tir desire

   SI   temps restant
          < -45 minutes
   ALORS sortie
          avec message
          operateur

   SINON calcule T0=heure depart poursuite (minute ronde)
          calcule P0=position de la consigne de depart
                      dans le fichier de consignes

          lance les taches appropriees et se desarme

immedia-   Poursuite
tement   3 secondes
                avant poursuite

```
=============
|INTERPOLATION|      =======      =======
|COMAND     |        |SYNCMS |     |DISSOR |
|ACTASS     |        |synchro.|    |ECHO   |
|ASSERV     |        |horloge |    |TRAISG |
|BOULE      |        |mise a l|    =======
|DCHARG     |        |efpf   |
=============        |et sort |
                     =======
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CORRECTIONS (G,S)
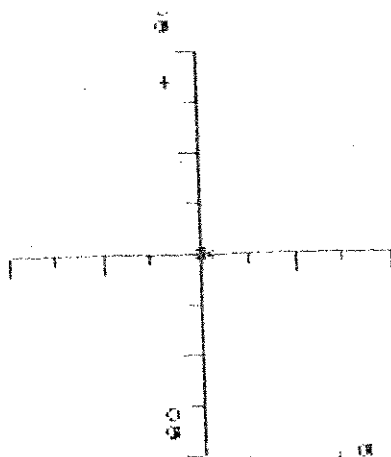
DECALAGE GENETIQUE   0
DECALAGE TRAJECT   0
BORNES MESURA   1994

RESIDUS

STATION LASER-SATELLITES DU C.E.R.G.A.   L86082004.46D

PMB :	0.0	
TS :	0.0	
H% :	0	
UTC :	0	

MOY. :	17253.246 ns
E.T. :	128. ps
CALIB. :	0. mm
CORDIS :	0. mm
E.R. :	21

- ECHELLE   FMOY   + ECHELLE

RESIDUS EN PS
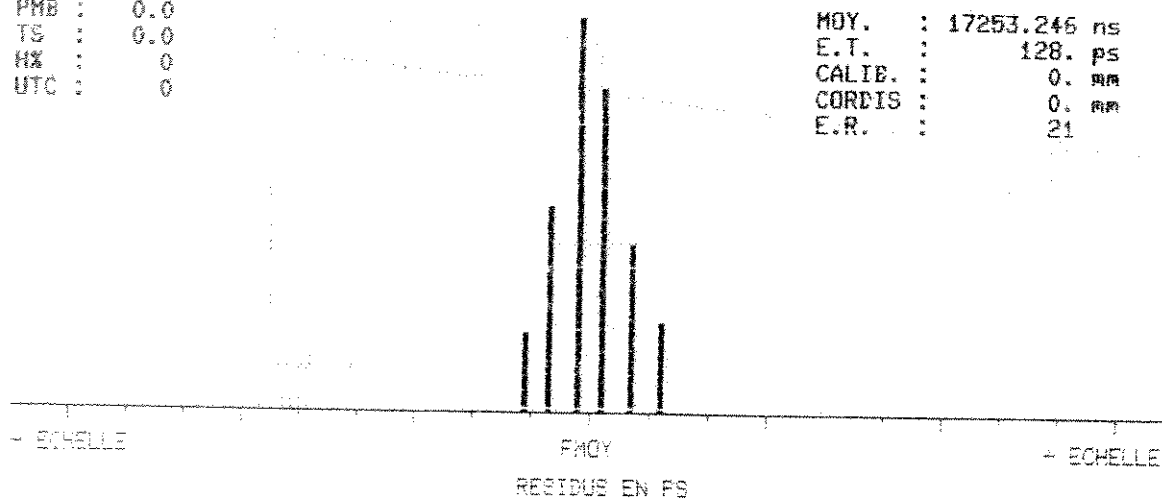
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coord. du maximum :   X= -44 ps   Y= 150 pts

STATION LASER-SATELLITES DU C.E.R.G.A.   L86082004.46D

PMB :	876.0	
TS :	18.3	
H% :	18	
UTC :	1	

MOY. :	17253.246 ns
E.T. :	128. ps
CALIB. :	26925. mm
CORDIS :	1268. mm
E.R. :	21

- ECHELLE   FMOY   + ECHELLE

RESIDUS EN PS
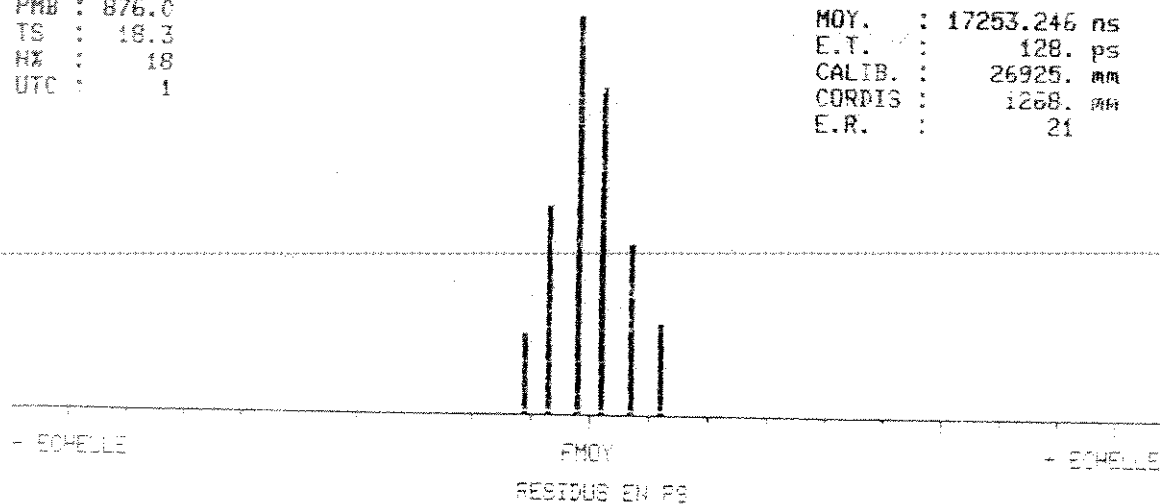
echelle :   2.000 ns   largeur des canaux :   22. ps
coord. du maximum :   X= -44 ps   Y= 150 pts

PRETRAITEMENT

+ 100m

- 100m

40mn
18sec

PRETRAITEMENT

+ 100m

- 100m

50mn
23sec

PRETRAITEMENT

+ 15cm

- 15cm

40mn
18sec
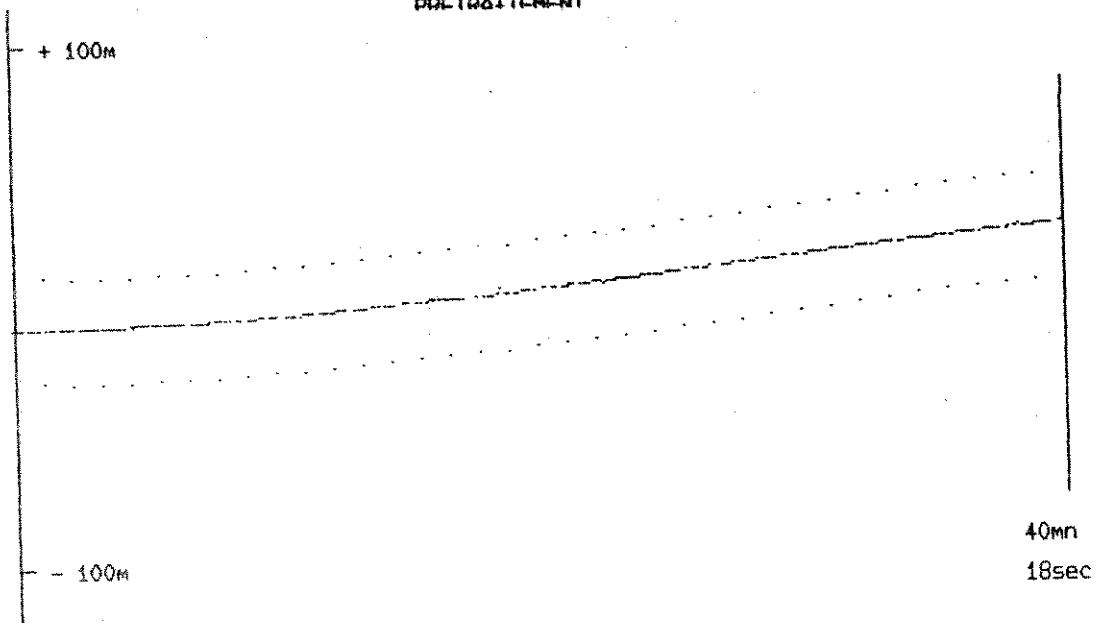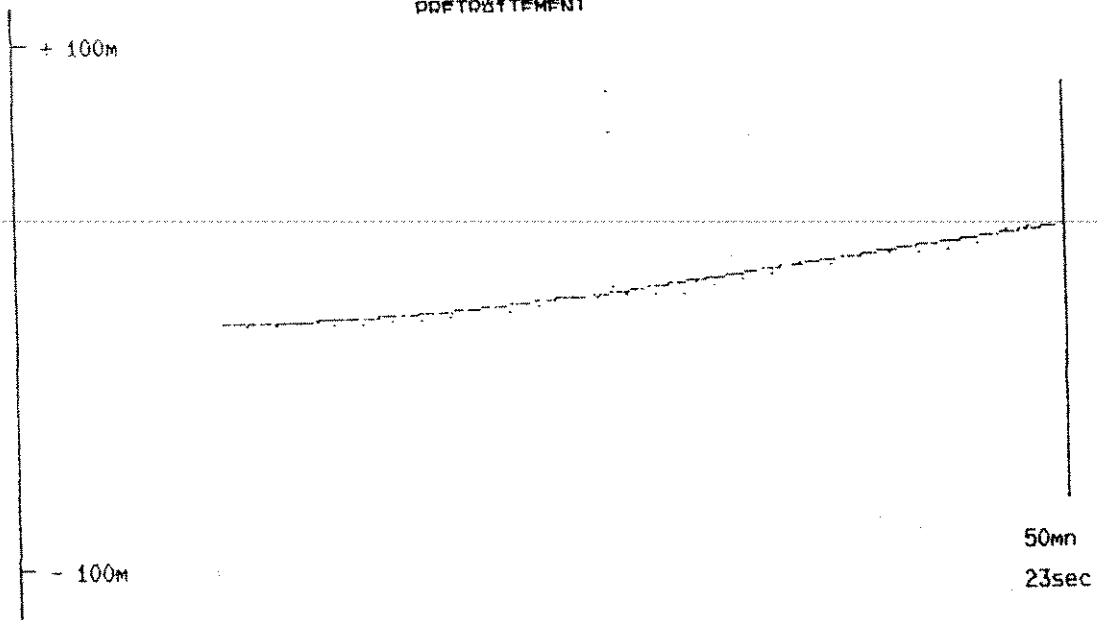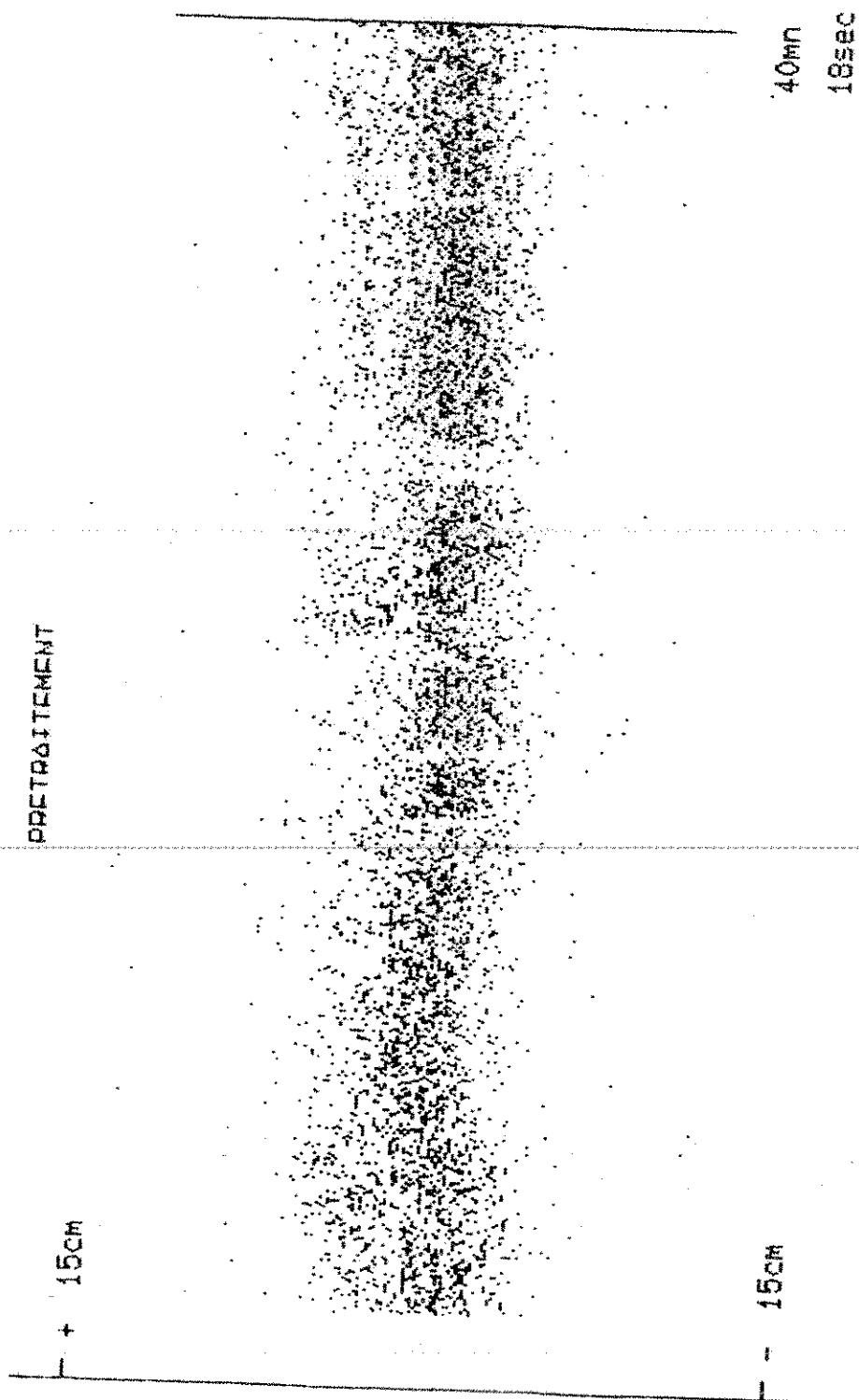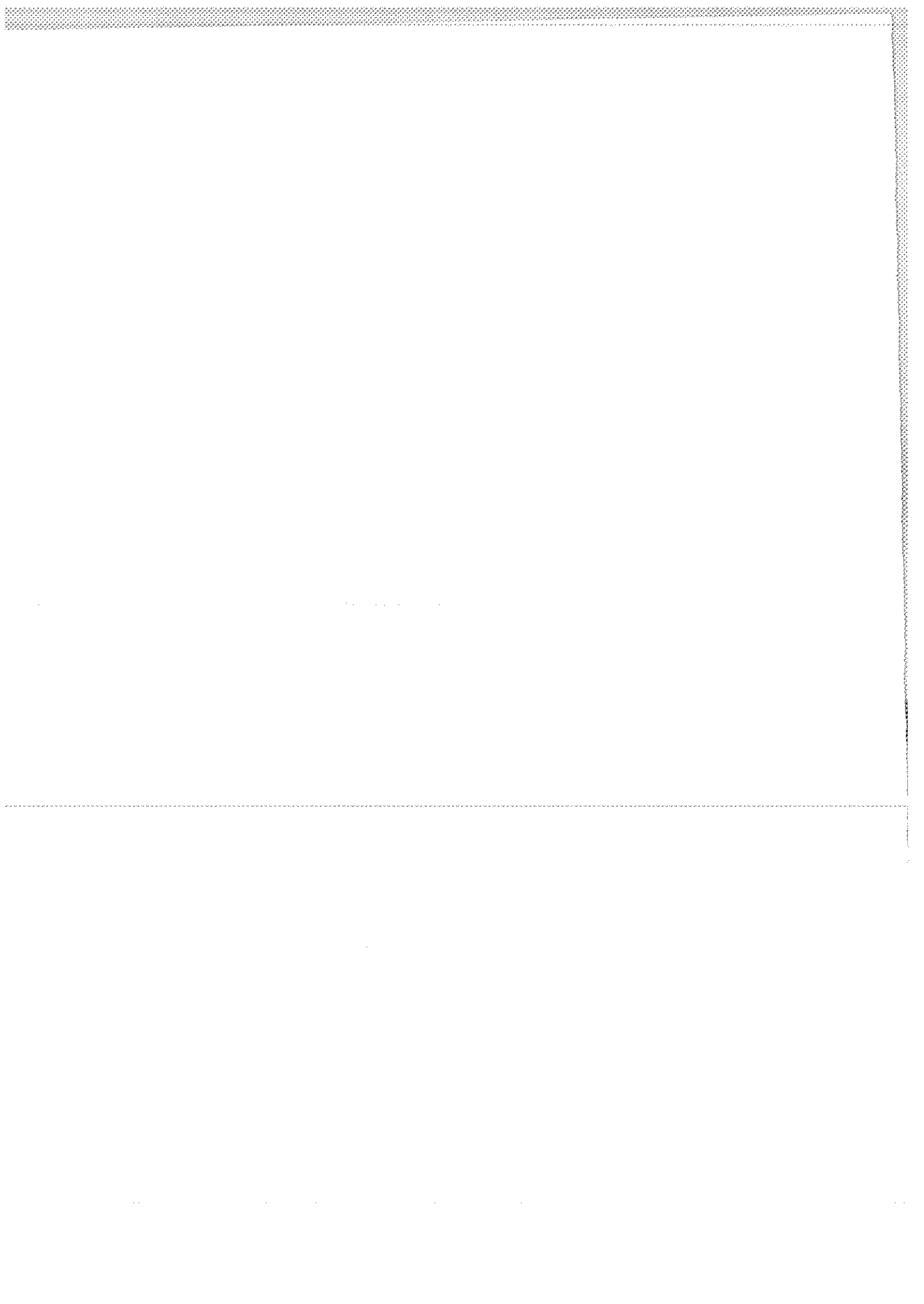
THE SBG LASER RADAR STATIONS POTSDAM AND SANTIAGO DE CUBA
STATUS AND PERFORMANCE REPORT

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Telex 15305

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ABSTRACT

The systems are based on a modified 4-axis satellite tracking camera (SBG). Their basic concepts and technical performance are typical for 2nd generation devices. Blind tracking of LAGEOS using narrow beams is possible with the help of a star calibration method. The systems are operated with 2nd generation performance since 1981 and 1985, respectively. The Potsdam station is contributing continuously to the MERIT project since 1980. LAGEOS tracking at Santiago station started in December 1985.

1. Station 1181 Potsdam

The SBG telescope was developed in the early sixties as a photographical tracking camera and was operated at Central Institute for Physics of the Earth (ZIPE) since 1966. In its basic construction, it was a Maksutov-Schmidt system (effective diameter of receiver optics 32 cm) on a 4-axis mount with axes no. 1 and 2 fixed and axes 3 (along track) and 4 (cross track) moved during operation. Along track movement was controlled by punch tape with an accuracy sufficient for photographic tracking of GEOS type satellites (SBG mount see Fig.1).

The main modifications to allow laser tracking with the SBG was to mount an additional hinged Cassegrain mirror in front of the photographical unit and to drill a central hole through the main mirror. In this way the receiver optics and related electronics could be placed behind this mirror. A two-stage passively Q-switched ruby laser was mounted on the main tube and moved together with the telescope. By inserting and re-placing the Cassegrain mirror, alternating photographical and laser observations became possible. This 1st generation system (laser pulsewidth 20 ns, visual tracking only) was operated successfully since 1974. First LAGEOS returns were obtained in September 1977.

Especially through the years 1979-81, the system was up-gradet to a 2nd generation device (possibility of automatic observations, ranging errors of a few decimeters for all existing laser satellites). The main hardware modifications were:
- Equipment of the 3rd and 4th axis with step motor drives and digital encoders for precise positioning, 2nd axis with a theodolite for accurate control of inclination.
- On-line computer control of the mount and related elec-tronics (digital range gate, laser firing etc.). For this purpose, an IEC 625 type interface with a desktop computer (8 - 24 kByte operational memory) as a controller is used.
- Replacement of the former laser transmitter (20 ns) by a 5 ns ruby laser [1].

There are some limitations in further upgrading the system: because of the optical-mechanical layout of the SBG mount there is no possibility to install a Coudé focus. So both laser and receiver have to be moved together with the mount beeing unfavourable especially for more sophisticated lasers with shorter pulsewidth. Additionally, the mount errors for a 4-axis mount are not so easy to handle and can be controlled exactly only by star calibrations limiting this method to night and twilight observations.

A program system for satellite position prediction, on-line mount control, data reduction and orbital elements improvement from own measurements was developed [2]. Additionally, from star observations an error model for the 4-axis mount can be derived leading to an absolute pointing accuracy of about

+/- 30" which is sufficient for most tracking purposes with wider diffraction angles of the laser. Totally blind tracking of LAGEOS using narrow beams (20 - 30") can be attained by observing the positions of some stars along the track of the satellite and finding the true setting angles of the mount by matching the observed and the catalogue positions of the stars via the computer. In this way the pointing accuracy can be improved to about +/- 10" which is strongly enhancing the reliability of LAGEOS tracking, especially using the long-term predictions of the LAGEOS position edited by the University of Texas [3] to produce osculating elements for the given pass.

The station 1181 Potsdam is contributing continously to the MERIT project since the short campaign 1980.

2. Station 1953 Santiago de Cuba

To improve the INTERKOSMOS station distribution of highly automated stations and according to the good experience with the Potsdam equipment, a second SBG mount was upgradet according to the main construction principles described above. Some slight modifications as enhancement of the laser output energy and simplification of receiver optics were done. The station was equipped in cooperation between G.D.R., U.S.S.R. and Cuba. After the installation in summer/autumn 1985, first performance tests were carried out during Dec.1985/Jan.1986 proving that the main performance data are similar to the Potsdam device. In Fig.2 and 3 typical range-noise histograms on a pass-by-pass basis for both stations are shown. For the Santiago station it was gained from the performance test period, for the Potsdam station it is derived from the whole MERIT main campaign. A comparison of some technical data between both stations can be found in Table 1.

Table 1: Technical data of SBG stations 1181 and 1953

Location	Potsdam, G.D.R.	Santiago de Cuba
Station number	1181	1953
Laser type	Ruby, TEM_{oo}	Ruby, TEM_{oo}
Pulsewidth/ns	5	5
Max. output/mJ	200	800
Min. divergency/"	20	20
Q-switch	Dye cell	Dye cell
Receiver type	RCA C 31034A	FEU 79
Quantum eff./% *)	10	3-5
Bus controller	HP 9825 S	EMG 666 B
Oper. memory/kByte	24	8
Time base	ZIPE time service (Cs-clock)	LORAN-C
First operation	March 1974 **)	December 1985

Remarks: *) $\lambda = 694$ nm
         **) First generation system

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    LAGEOS Ephemeris Predictions
    Proc. 4th Intern. Workshop on Laser Ranging Instr., vol.
    Edt. by P. Wilson, Bonn (1982), p. 145-71
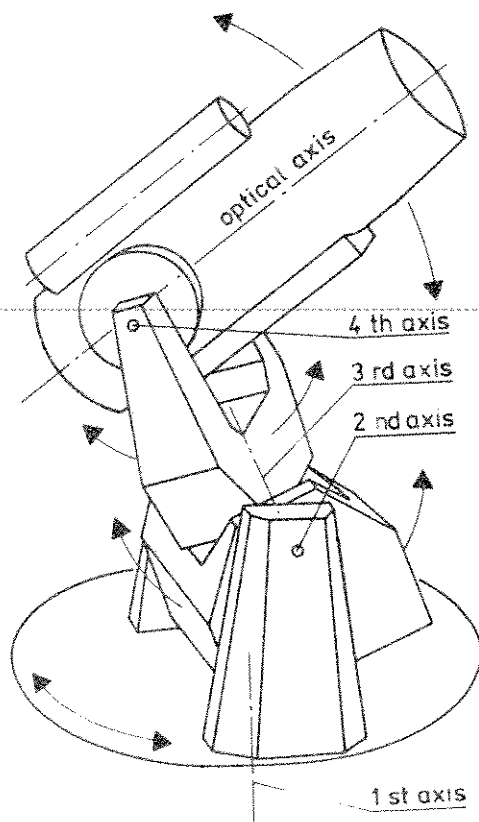
Fig. 1
Schematic drawing of the SBG - mount
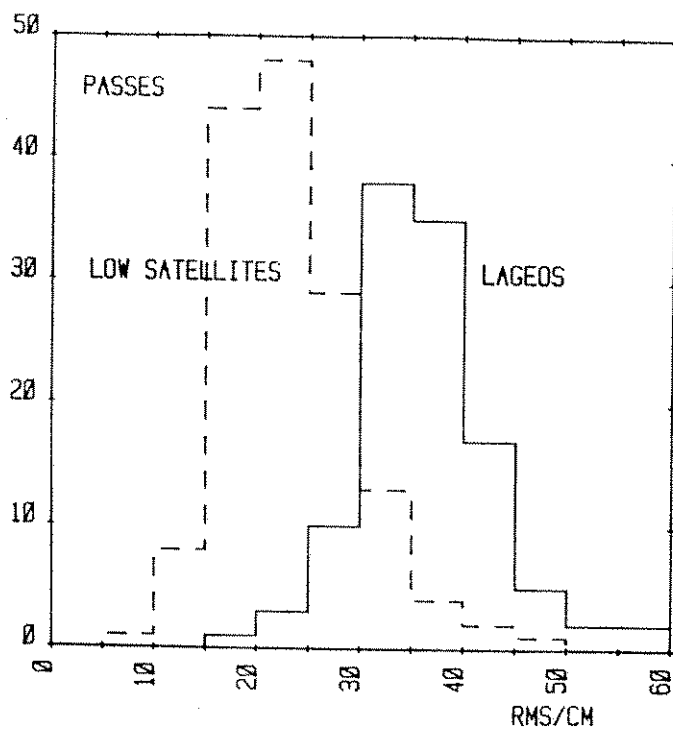
Fig. 2: Pass-by-pass range noise histogram for station 1181
Potsdam, data from the MERIT main campaign
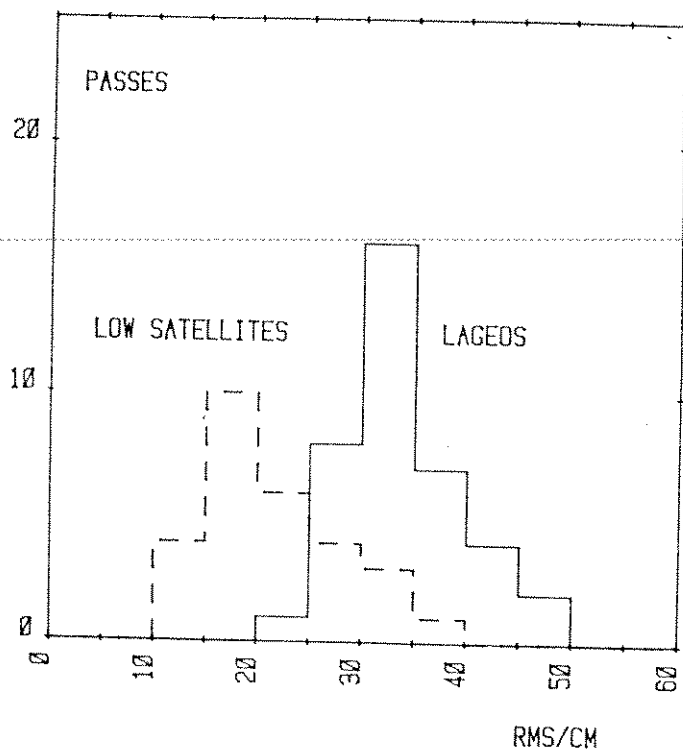
Fig. 3: Pass-by-pass range noise histogram for station 1953
Santiago de Cuba, data from performance test period
December 1985 - January 1986
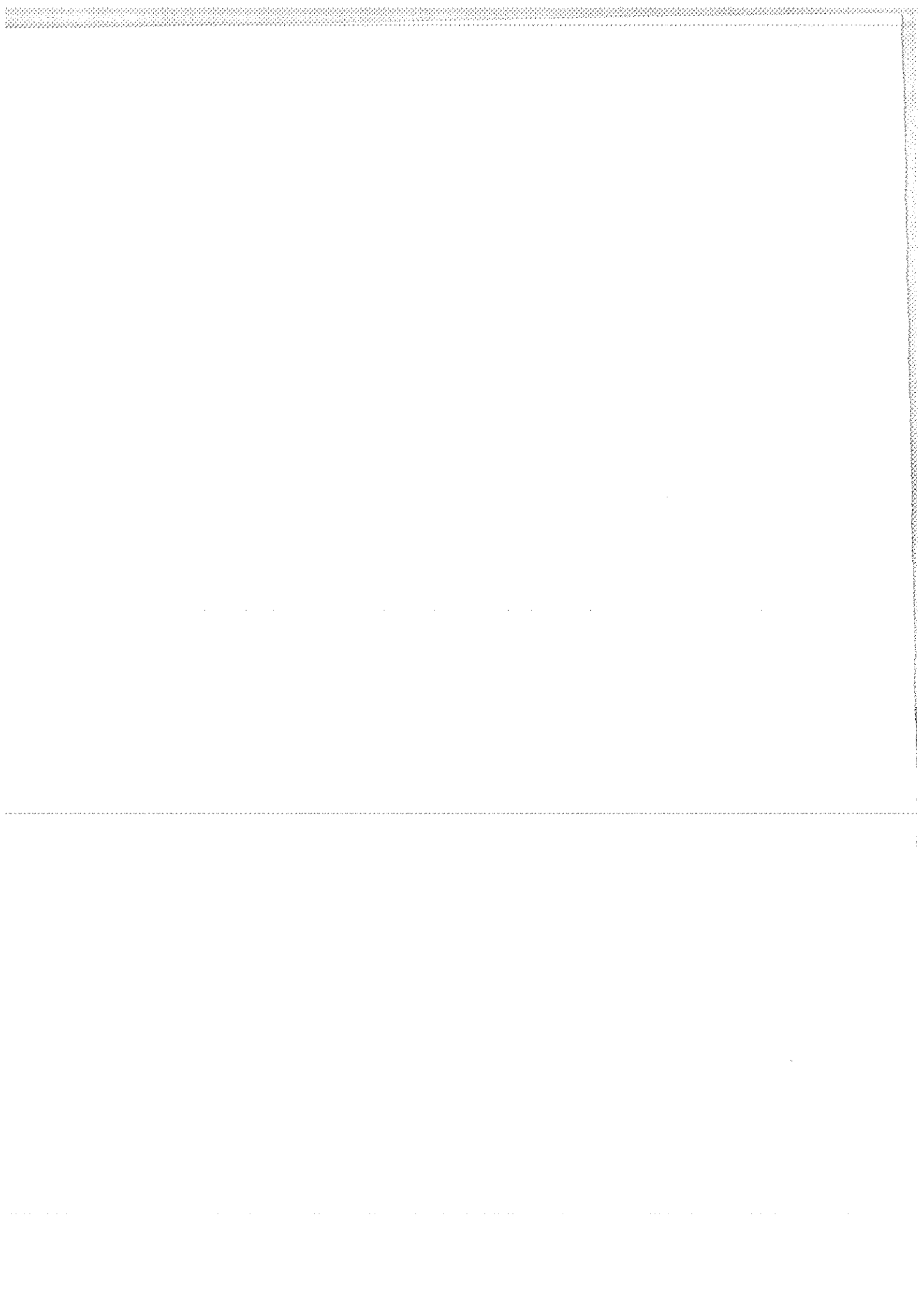
AMBIGUITY AND RESOLUTION OF A MODE-LOCKED
PULSE TRAIN LASER RADAR

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Telex 15305

ABSTRACT

The accuracy of a multipulse laser radar has been studied with indoor experiments and computer simulation. For the experiments a mode-locked Nd-YAG laser producing 7 to 9 pulses of 4.6 ns spacing at 10 Hz repetition rate is used. The frequency-doubled pulses are divided by a beamsplitter and recombined at the photomultiplier which is working at the single photoelectron level. The time-of-flight data are treated by cross-correlating the empirical distributions corresponding to the two light paths. This leads to an estimate of the time-of-flight difference. Using a large amount of data sets, the following parameters are determined:
a) the percentage of estimates shifted by more than half a
   pulse spacing
b) the standard deviation of the unshifted estimates.
For the parameters of our system, the percentage of "good" estimates is higher than 90% if more than 200 measurements are used. A standard deviation of about 100 ps is obtained under the same conditions. These results are obtained using electrostatic PMT's with about 500 ps jitter.
Good agreement between the experiments and computer simulations is found. Thus the simulation method is used to determine the system performance in a wider parameter range.
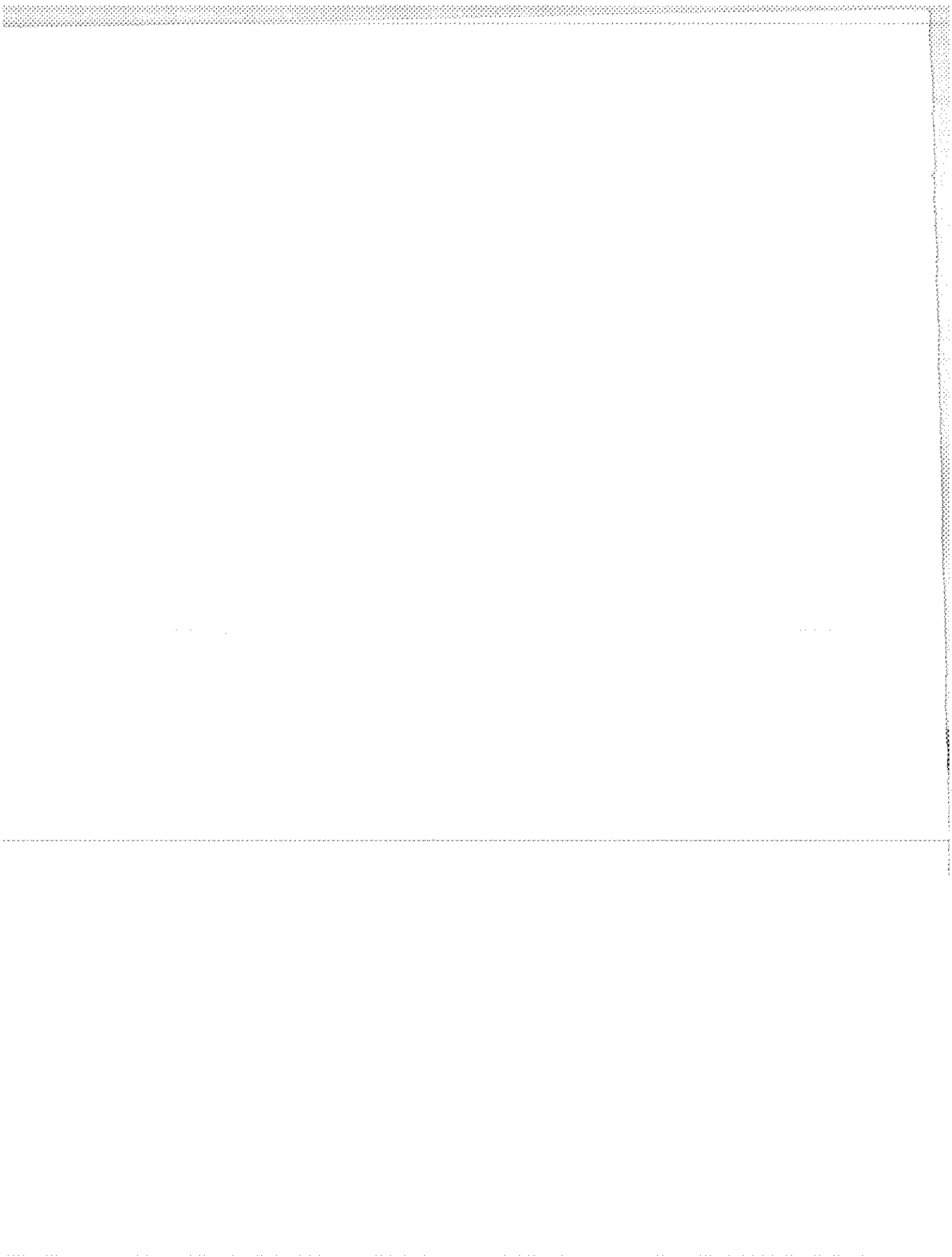
Fernsehelektronik Berlin). Assuming that the start- and stop-time fluctuations are equal and independent in this case, the RMS start-time noise can be calculated to be 100-140 ps. For the experiments with PMT receiver, the SP 109 was always used. Thus, the jitter of the RCA C 31034A can be estimated by quadratic subtraction of the start noise to be around 350 ps. From this example it can be seen, that the start-time noise has only small influence on the overall resolution in our experiments.

The precision of the cross-correlation method

The generally adopted method for treating the data of a mode-locked train laser radar is to calculate first the frequency distributions of the calibration- and the ranging-measurements separately, and then to determine the time shift for maximum correlation of the two distributions. An example distribution is shown in Fig.2. The two subdistributions according to path 1 and 2 are well separated from each other by roughly 60 ns. Convoluting both distributions, Fig.4 was obtained. In this figure the convolution sum is plotted like a polygon linking the points separated by the bin width of 250 ps. The maximum can be determined very accurately using some interpolation method. In our case we obtain for the time shift of maximum correlation (61.16 ± 0.1)ns.

To investigate the precision of the method, the measurements of this and several other experiments were arranged into groups. Then the cross-correlation method was applied to each group so that an ensemble of time shifts is obtained from which statistical estimates for the precision can be gained. The parameters under consideration are:

1. the percentage of time shift results deviating from the real value not more than half a pulse separation (this quantity called "uniqueness")
2. the RMS error of the results deviating not more than half a pulse separation

These parameters are plotted in Fig. 5 and 6 in dependence of the quantity of measurements. As a normalized measure of the data quantity we are using $(1/n_1 + 1/n_2)^{1/2}$, where n_1 and n_2 are the number of measurements for path 1 and path 2, respectively. This is just the probable error of the ranging average for a single pulse system, expressed in terms of the standard deviation of a single time interval measurement. To estimate the uniqueness (resp. ambiguity) and precision from the measurements, 10 runs of 1000 points each are used. The total ensemble of 10000 measurements is arranged into groups of $n_1 + n_2 = 60, 120, 240, 480$ individual measurements. For each group the cross-correlation method is applied resulting in the generation of an ensemble of ranges from which the interesting average parameters are estimated. The return rates for the two light paths are slightly changing

from run to run. Therefore averages for the parameter
$(1/n_1 + 1/n_2)^{1/2}$ have to be determined also. The resulting
experimental values for the uniqueness and precision are
plotted with the symbol "+" in Fig. 5 and 6.

For comparison with theoretical values and to obtain more
general results (including different shapes of the laser
signal like reduced pulse numbers), computer simulations were
carried out assuming the photodetection process to be de-
scribed by Poisson statistics and the timing jitter to have
a Gaussian distribution. The simulator is a pseudo random
number generator which outputs two possible numbers:
0 (corresponding to no detection) and 1 (detection). The
probabilities of the two states are determined by the average
number of photoelectrons (s) of the pulse according to:

$$P(0) = \exp(-s) ; \quad P(1) = 1 - \exp(-s)$$

The simulator is called for each consecutive pulse of the
group using the pulse intensities as input parameters. When
the first positive answer occurs, the corresponding pulse
number is stored together with some added Gaussian timing
noise. By repeating this process, 5000 simulated time inter-
vals for both the calibration and the ranging channel are
generated and stored into the memory. In this process, the
average return rate for the calibration is set to be 50% and
for the other channel 25%.

To estimate now the performance parameters of the system
in dependence on the amount of measurements, example reali-
zations are selected from simulated measurements and then
treated by the cross-correlation method in the same way as
is done with the real measurements.
The selection of the individual values from the memory is
done by calling an equally distributed pseudo random number
generator to determine the addresses. 500 example reali-
zations are used to estimate the performance parameters, i.e.
the uniqueness and the RMS error of a cross-correlation re-
sult.

To compare the experimental values with the simulations,
the average shape of the time interval histogram is needed.
It has been approximated by 9 Gaussian peaks with Gaussian
envelope according to

$$h = a_0 \sum_{k=-4}^{4} \exp(k^2/U) \cdot \exp((t - t_k)^2/2\sigma^2) . \qquad (1)$$

The average experimental parameters are $U = 4.61$, $\sigma = 386$ps.
The separation of consecutive pulses is

$$\Delta t = t_{k+1} - t_k = 4.55 \text{ ns.}$$

So the relative resolution is $C = \sigma / \Delta t = 0.0848$.
Using these parameters the results marked in Fig. 5 and 6 by
"*" are generated. They agree reasonably well with the experi-
mental points, especially for the uniqueness (Fig.5). This

agreement is somewhat surprising because the laser pulse shape fluctuations are not directly modelled in the simulations. Instead, the pulse shape is chosen in agreement with the observed histograms. Note further that the simulated results showed almost no dependence from n_1 / n_2 if the above introduced parameter $(1/n_1 + 1/n_2)^{1/2}$ is kept constant. This is proved in the range $n_1/n_2 = 1...10$.

For the conditions used in our experiments, the following conclusions can be drawn:
- the performance of the system can be reasonably well determined by the described simulation method
- 200 measurements for both calibration and ranging are required to have 90 per cent probability of correct assignment of the data (not shifted by a multiple of the pulse separation)
- the standard deviation of a result generated from 200 measurements is in the order of 100 ps.

The good representation of the experiments by the simulation encouraged us to study the dependence of the system performance from the laser pulse shape and the timing resolution more detailed. Some of the results are graphically represented in Fig.7 and 8. In these figures, both the uniqueness parameter (broken lines, 1 at the vertical scale corresponds to 100%) and the ratio of the RMS error of the cross-correlation result to the single-shot timing jitter (full lines) are plotted in dependence on the amount of measurements. The relative RMS error as defined describes the effect of averaging.

In Fig.7 for a fixed laser pulse shape the influence of the timing resolution is represented. As a measure of the resolution, the parameter C (defined as the ratio of the overall RMS jitter of the timing system to the pulse separation of the laser pulses) is used. The time resolution is visualized by the probability distributions of the time intervals, i.e. the shapes of the histograms for very large amounts of measurements.

As can be seen from Fig.7, the timing resolution has a very small influence on the uniqueness (resp. ambiguity) but some effect on the relative RMS error. This behaviour is to be expected. We conclude from Fig.7 that the resolution parameter C should be smaller than 0.2. Note that for a given resolution of the timing system, the parameter C can be adjusted by the separation of the laser pulses which is possible by choosing the laser resonator length.

The number of pulses in a laser pulse group is represented by the parameter U. More precisely, this is the overall width of the probability distribution of the time intervals according to equ.(1). The parameter U is chosen to be U = 6 in Fig.7.

The dependence of the system performance on the parameter U

for a fixed resolution (C = 0.1) is shown in Fig.8. As expected, the parameter U has almost no effect on the error, but strong influence on the ambiguity. Fig.8 may be used to determine the amount of data to reach a given uniqueness level. A uniqueness of 90% in connection with U = 2 is reached for $n_1 = n_2 \approx 50$. For U = 1 only 20 measurements are needed in both channels to reach 90% uniqueness. There are some methods to minimize the parameter U including laser design, the combined use of nonlinear optical effects and well matched start detectors. With generally available technology, U = 1...2 should be a realistic value.

Conclusion

From the results of this study we conclude that the mode-locked train laser radar remains to be an attractive variant. Its main limitation, the ambiguity, can be reasonably overcome using a sufficient data quantity. The minimum data amount for a given probability of correct assignment can be gained from this paper. As a guide to good performance, one should restrict the number of pulses per group to a minimum and adjust the pulse separation to roughly 10 times the timing jitter. A special advantage of the rigorous use of single photoelectron detection is the low level of systematic errors. This gives the possibility to attain normal point errors near 1 cm even by using conventional electrostatic photomultiplier tubes.

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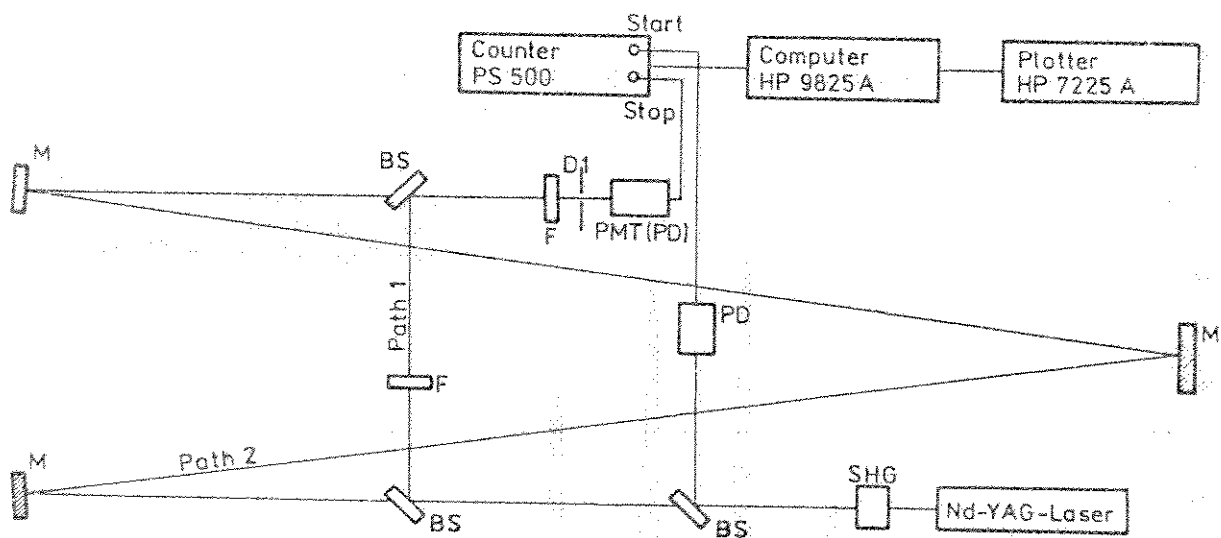
Fig. 1: Scheme of the experimental setup
   BS - beam splitter, D - diaphragm
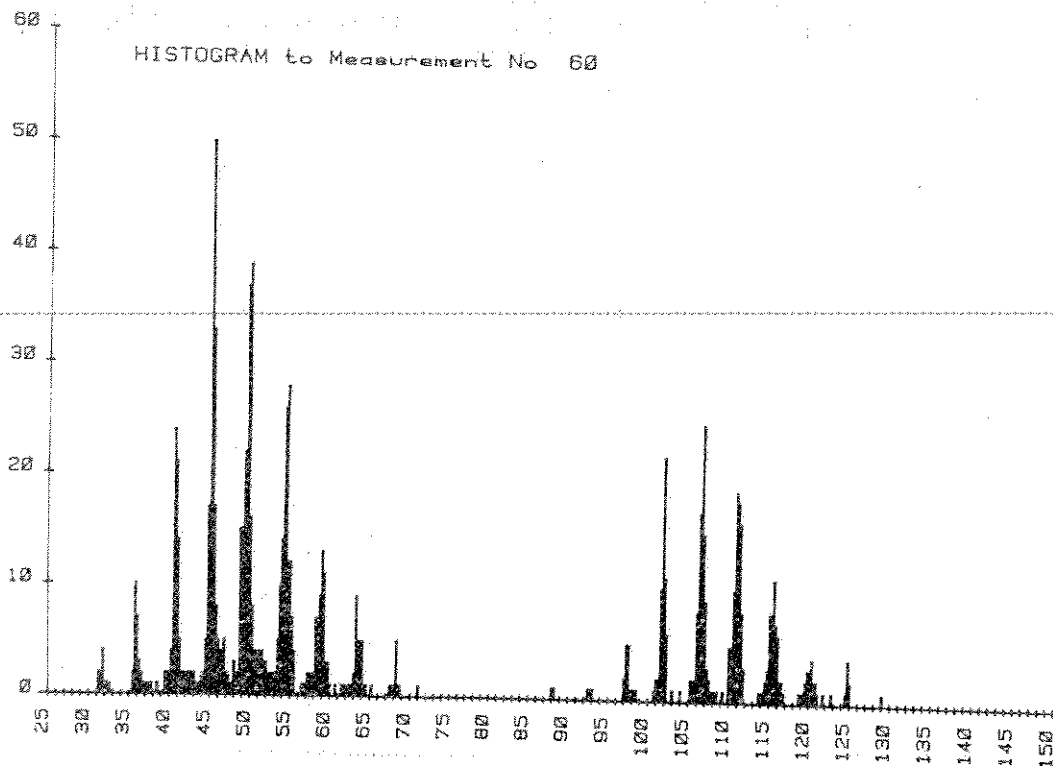   F - neutral density filter, M - mirror
   PD - photo diode

Fig. 2: Histogram of the time of flight values for a typical
   ranging experiment
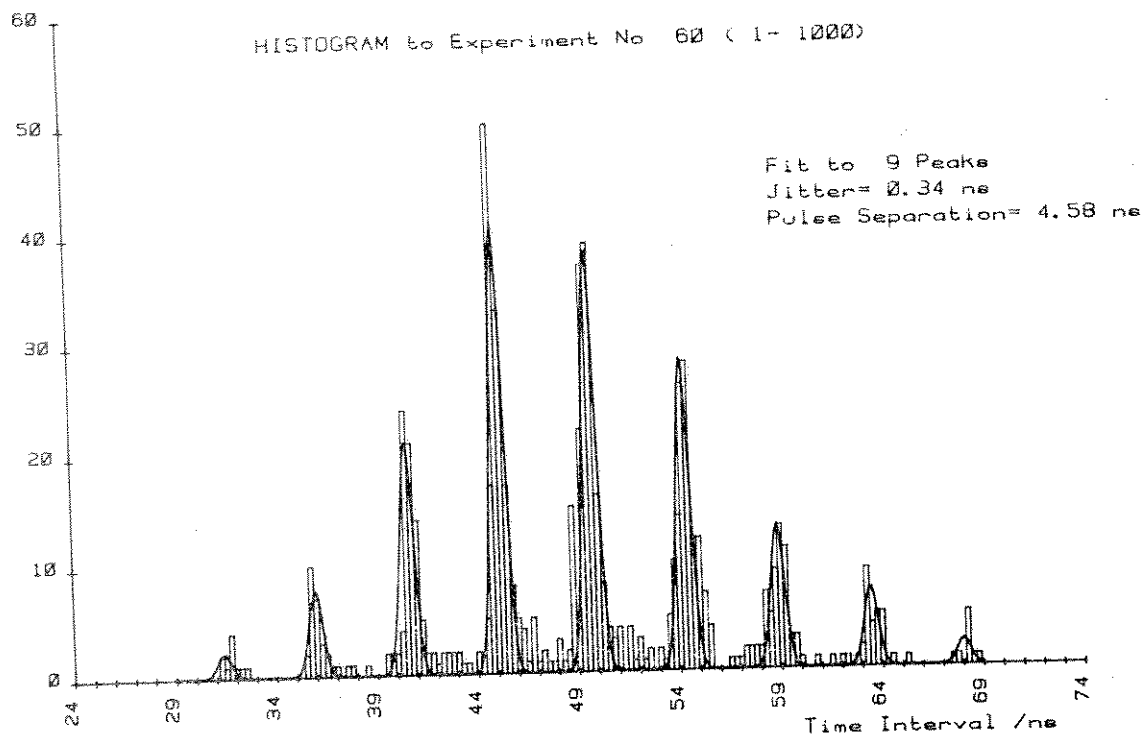   Abscissa: Time interval in ns
   ordinate: Number of measurements

HISTOGRAM to Experiment No 60 (1- 1000)

Fit to 9 Peaks
Jitter= 0.34 ns
Pulse Separation= 4.58 ns

Time Interval /ns

Fig. 3: Least square fit of a sum of Gaussian functions
to the calibration part of experiment No. 60 (Fig. 2)
bin width: 0.25 ns, RMS resolution: 0.34 ns,
peak separation: 4.58 ns
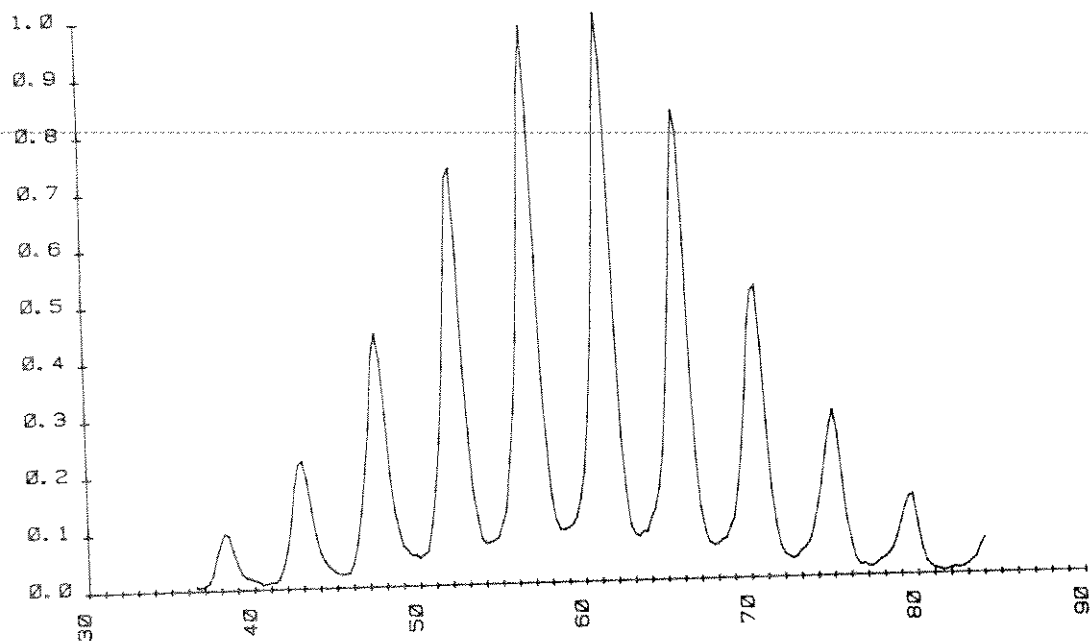
Fig. 4: Empirical cross-correlation to experiment No. 60
(convolution sum of the histograms corresponding
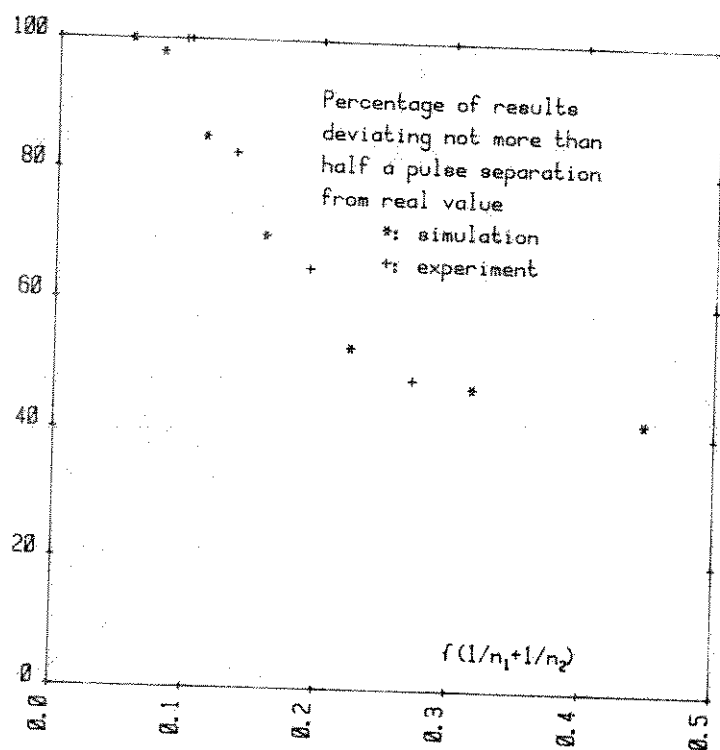to ray path 1 and 2 resp.)

Fig. 5: Uniqueness in dependence of the amount of measurements: comparison of experiment and simulation.
n_1 - number of measurements for path 1
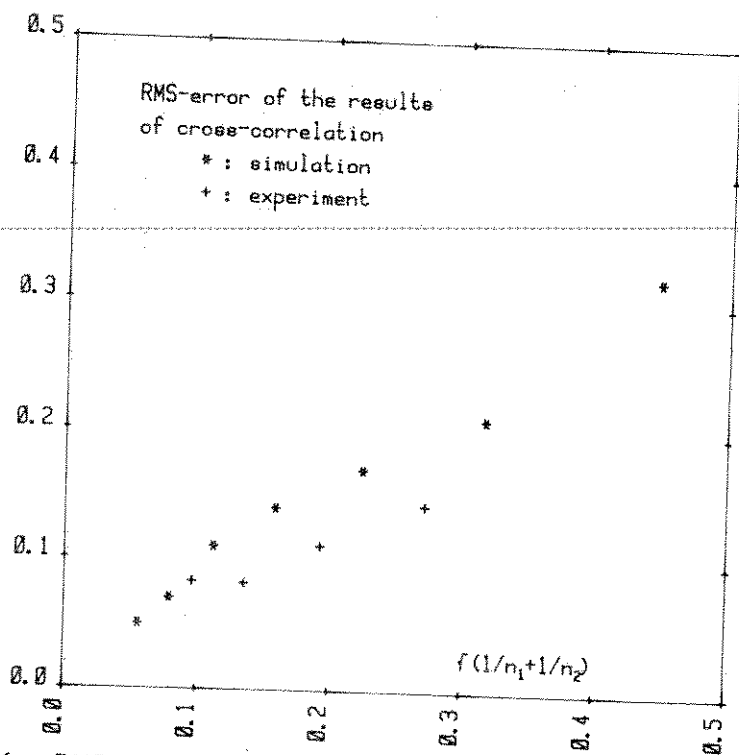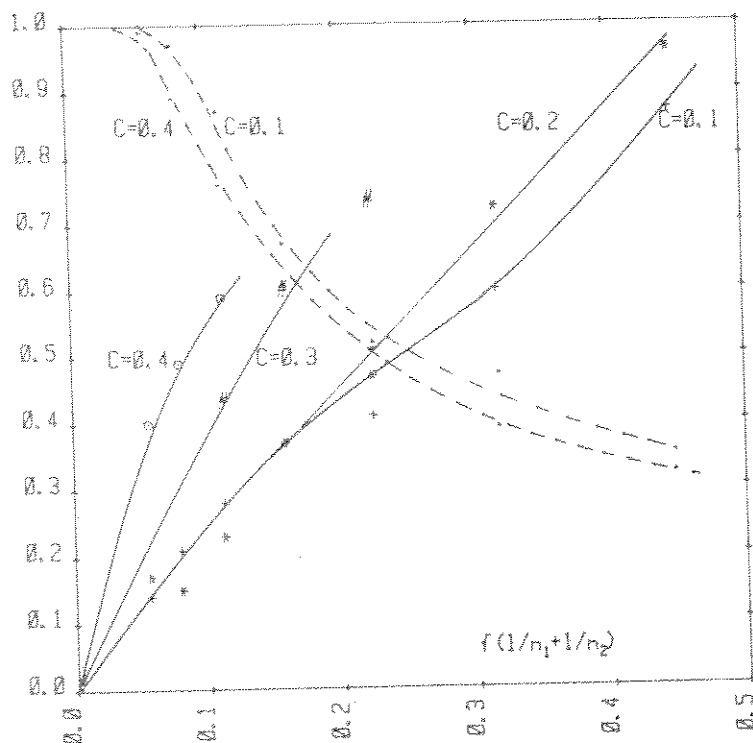n_2 - number of measurements for path 2

Fig. 6: RMS-error of the time shift corresponding to maximum cross-correlation: comparison of experiment and simulation

Laser radar performance
for different probability
distributions of the
time intervals
--- uniqueness
— rms/Jitter
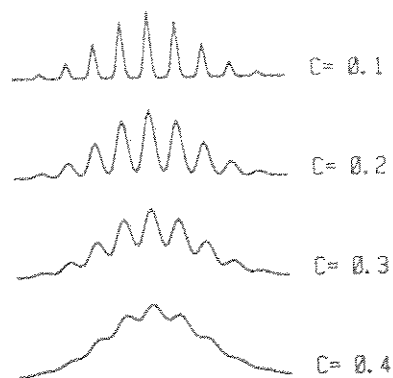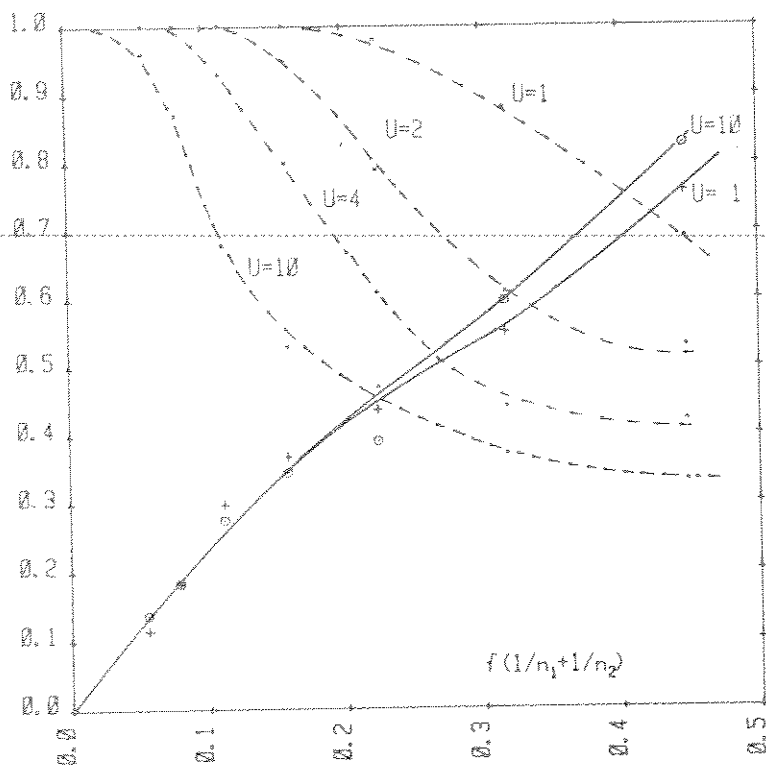Envelope Param. U=6

C= 0.1
C= 0.2
C= 0.3
C= 0.4

Fig. 7: Uniqueness and error obtained from simulations:
dependence from timing resolution

Laser radar performance
for different probability
distributions of the
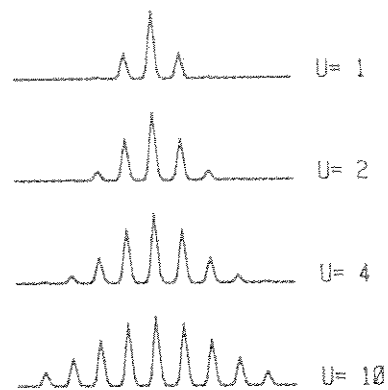time intervals
--- uniqueness
—— rms/Jitter
Jitter: C=0.1

U= 1
U= 2
U= 4
U= 10

Fig. 8: Uniqueness and error obtained from simulations:
dependence from the number of peaks

3.GENERATION LASER RADAR, VERSION MODE LOCKED TRAIN PROPOSAL

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ABSTRACT

To range the satellites and the Moon at the 3rd generation level
(rms<9 cm), laser transmitters generating mostly single pulse are exploited.
Following the idea of E. Silverberg (4WLRI, 1981) and B. Greene (5WLRI, 1984)
we propose to exploit the full train of mode locked pulses. The simplifi-
cation of the laser transmitter is tremendous, the laser output average power
may be 3 to 5 times higher for the same material damage threshold. To avoid
the ambiguidity in range determination we propose to use the tranzient digi-
tizers as the START/STOP discriminators. The ambiguidity is removed by START/
STOP signal crosscorrelation on the shot by shot basis for satellite/multi-
photon/ranging. Assuming the Moon ephemeris quality, the possible ambiguidity
in Moon ranging at single photoelectron level may be removed by ranging data
processing.

REQUIREMENTS : RMS single shot (3cm (200 picoseconds)

JITTER budget main contributors - detector
 - laser pulse
 - discriminator

DETECTOR jitter contribution :

RMS /multi PE detection/ $\qquad \sqrt{[pulse\ energy]}^{-1}$

Normal point accuracy $\qquad \sqrt{[average\ power]}^{-1}$

PROJECT PROPOSAL

LASER - mode locked train,3-5ML pulses, pulse HAFW 30psec

DETECTOR - microchannel PMT

DISCRIMINATORS - Tranzient digitizer /Tektronix 7912AD/
 bandwidth 400MHz, 10mV/div sensitivity
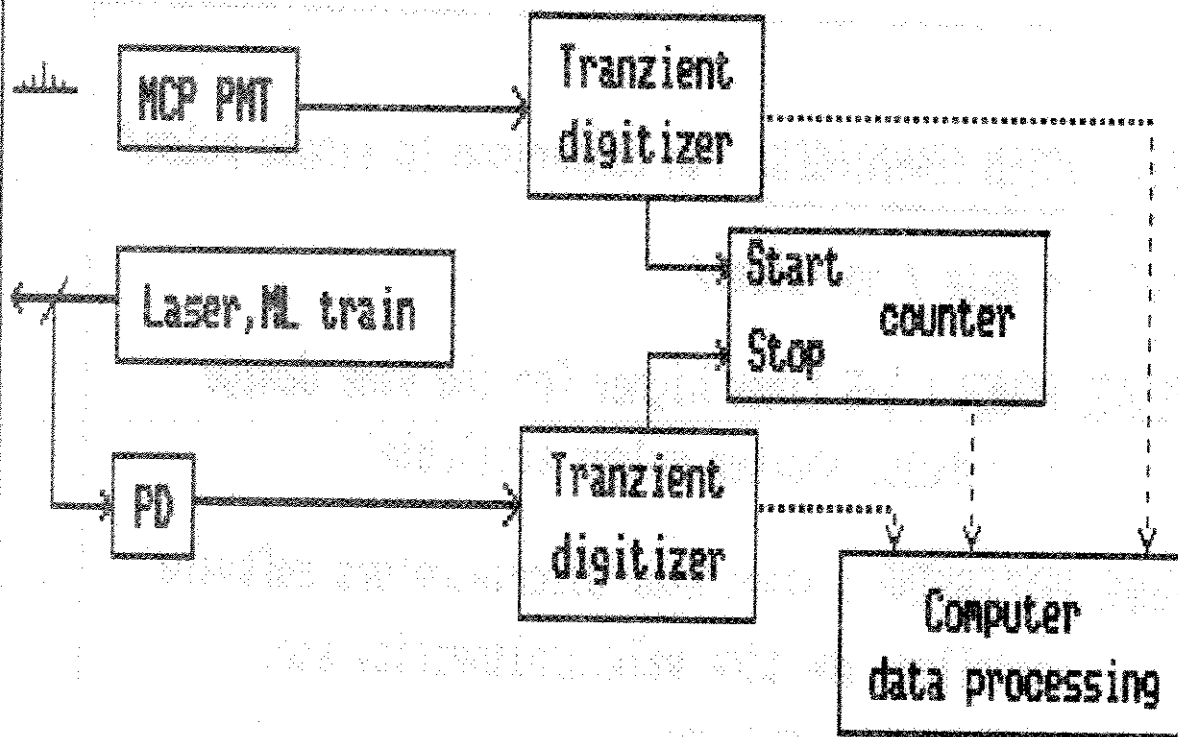 discriminators software modelled
 nonlinearities compensated
 Start/Stop events data crosscorrelated

Proposed block scheme

MCP PMT → Tranzient digitizer		
Laser, ML train	Start / Stop counter	
PD → Tranzient digitizer		Computer data processing

—————— signal pass
.... data flow

Jitter contributions:		multi PE	single PE
photomultiplier	(MCP)	65 psec	100 psec
tranzient 2x + PD		30 psec	30 psec
counter	(HP5370B)	35 psec	35 psec
laser pulse	(fwha30ps)	(3 psec	12 psec
RESULTING		80 psec	110 psec

K.Hamal, I.Prochazka
3.Generation/version mode locked train/proposal

2

Summary / conclusion

PROPOSED SYSTEM ADVANTAGES: /in comparison to single pulse/

* LASER : simple / no slicer/

* AVERAGE POWER : 3-5 times higher for the same damage
  threshold, shorter pulses available

* SIGNAL PROCESSING : start/stop discriminators software
  modelled, the time walk, nonlinearity etc.
  software compensated

* CALIBRATION : both real time and pre/post pass possible,
  the signal strength is not critical

* AMBIGUIDITY : due to the ML train
  satellite / multi PE ranging /   NO
  Moon /single PE, excellent epheneris/   LOW/NO

PROPOSED SYSTEM LIMITATIONS /in comparison to single pulse/

* DATA QUANTITY : additional 2 x 1 KBytes per shot

* SOFTWARE : more complex, data processing time consuming

K.Hamal, I.Prochazka

3.Generation/version mode locked train/proposal   3

THE NEW SATELLITE LASER RANGING SYSTEM
AT CAGLIARI OBSERVATORY

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ABSTRACT

About one year ago the restructuring of our laser station was begun, with the technical assistance of the Vitroselenia Company of Cagliari.

The work consists of the total substitution of tracking, control and data acquisition equipment.

In carrying out the work the prime consideration was that of the reliability and precision of each single component.

The new station is expected to become operative in the first months of 1987.

1. TRANSMISSION-RECEPTION PULSES SYSTEM

At present we have available a first-generation Q-switched Ruby Laser that was custom-built for us by Apollo Lasers Inc.

This system remained inactive for about three years for various reasons, most of which of a technical nature.

Therefore we are now in the process of verifying the efficiency of the Pochels Cells assembly, the Q-switching system, the optical alignments, the electrical system and also the tracking system (fast diode, PMT, signal amplifiers).

The characteristics of our Ruby Laser Transmitter are given in Table 1.

For the transmission and reception of the laser shot we use a single reflector telescope of the Cassegrain-coude type, the lenses of which were made in Florence.

In the previous system, transmission, reception and TV control were carried out by means of three distinct telescopes, with consequent problems of mechanical inertia, optical alignment and electromechanics.

We therefore designed an optical diagram that couples the three optical paths with the use of dichroic mirrors and beam splitters with minimum variations in the percentage of signal power loss.

As for mounting, we have available the base of a Contraves EOTVOS-B cinetheodolite the electromechanical components of which have been replaced, partly because they were obsolete and partly because they had deteriorated.

The characteristics of the telescope are given in Table 1 and the optical diagram is described in Figs 1a and 1b.

Table 1

RUBY LASER SPECIFICATION

|	
Oscillator Rod	1x7.5 cm AR coated ruby
Amplifier	1.3x15 cm AR coated ruby
Q-Switch	1 cm clear aperture, KD*P pockels cell
Cavity configuration	Flat-Flat, pulse-on switching
Wavelength	694.3 nm
Line width	0.3 A fwhm typical
Output Energy	1 Joule in 5 ns pulse width
Beam divergence	3 mrad
Repetition Rate	60 per minute, maximum
Main Mirror	50 cm Quartzand aluminium
Equivalent Focal Length	5 m
Field of View	0.0003-0.006 mrad

VIDEO

PMT

RUBY LASER
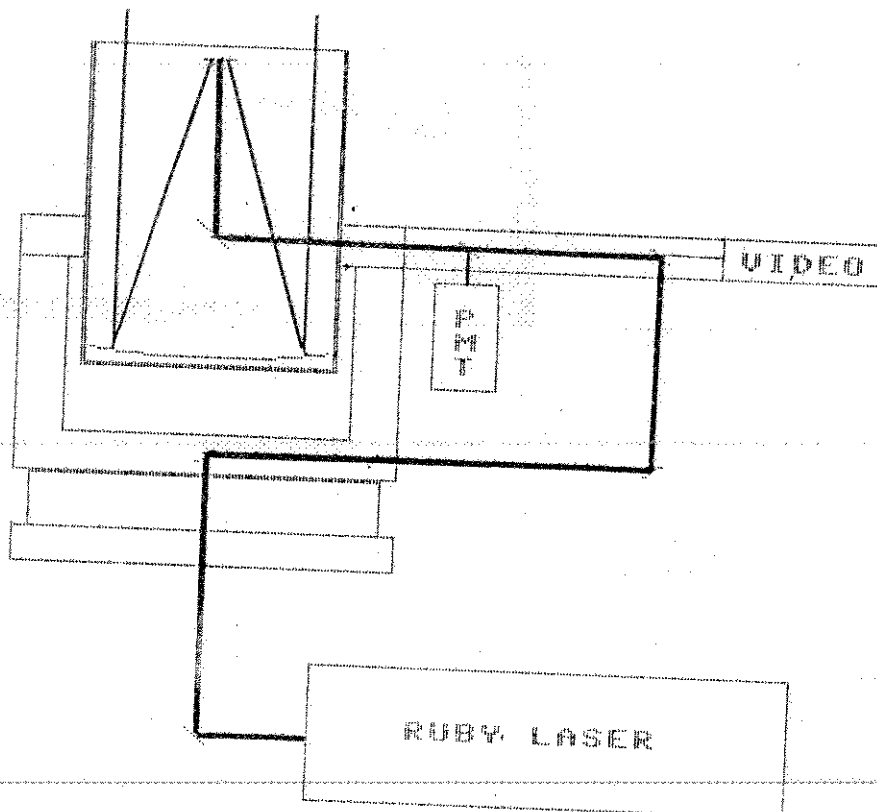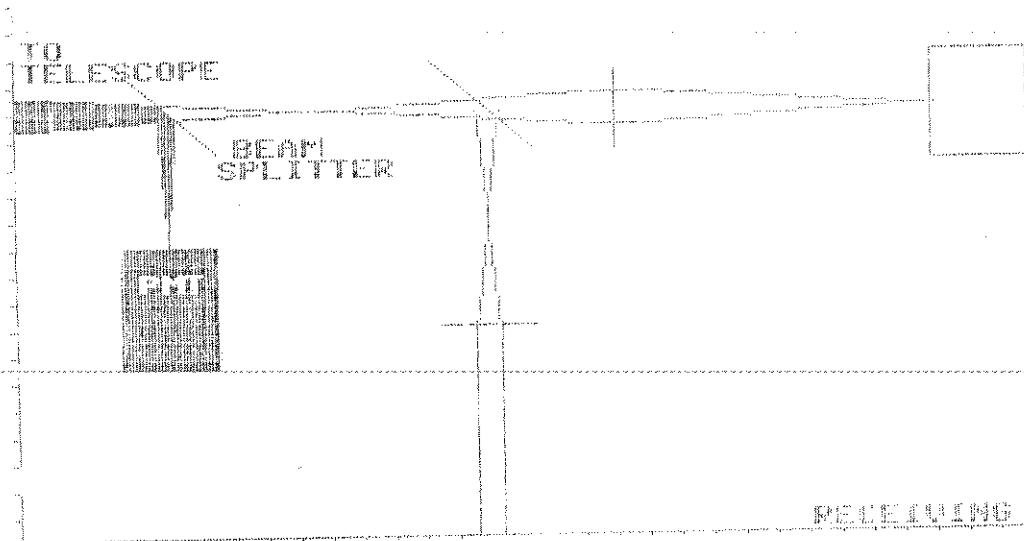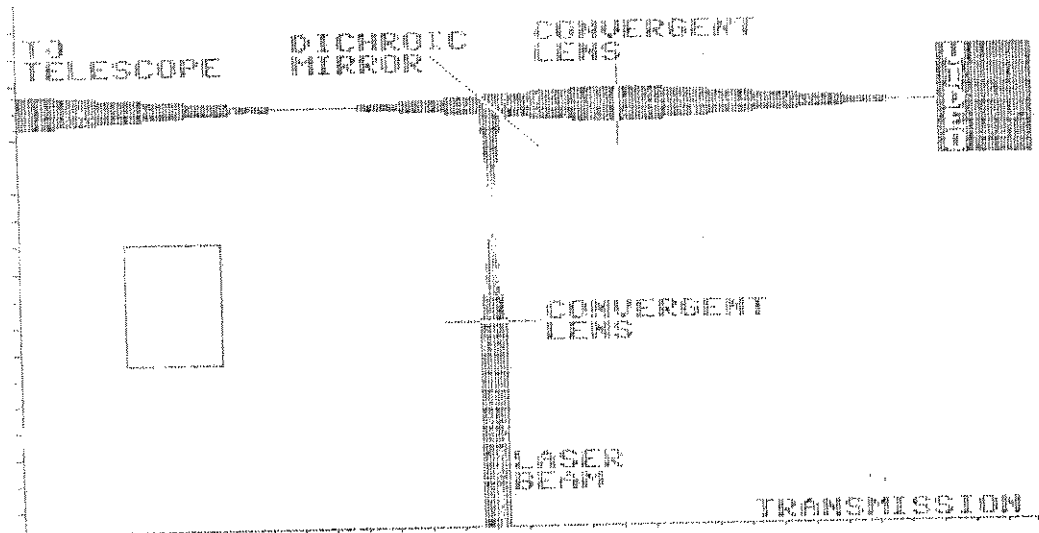
FIGURE 1a
OPTICAL DIAGRAM

FIGURE 1b

2. FOLLOWING MOVEMENTS

For azimuth and elevation drives the cinetheodolite was equipped with servomotors of the type with direct current and low inertia which are coupled to the axes with gear wheel - worm screw couples.

The motors for following are driven by servoamplifiers and their speed is read by speedometer dynamos.

The speedometer dynamos, which make up the velocity feedback towards the servoamplifiers, are keyed on the same axis as the motors themselves.

The guiding servoamplifiers, built with LSI technology, are switching converters with bidirectional, high-speed response pulse wave modulation (PWM).

The controls are governed by a microprocessor which carries out the following duties:

- -Control of the drive units
- -Acquisition of angle data
- -Closing of speed and position loops
- -Limit switches
- -Dialoguing with computer personnel

The microprocessor directly governs the function of following control by means of the position feedback supplied by the encoders.

The azimuth and elevation encoders used are of the absolute type with a 16 bit angular resolution; they consist of an optical-mechanical part and a card containing all the electronic interfacing to the data acquisition and control microprocessor.

In order to optimize the angle readings the encoders were installed close to the two rotational axes with a system for the taking up of mechanical play such as to guarantee aim accuracy with a tolerance of <0.1 degrees.

Table 2

SERVOMOTOR AND ABSOLUTE ENCODER

NOMINAL TORQUE	77 Ncm
NOMINAL EFFECTIVE POWER	240 Watt
SPEEDOMETER DYNAMO LINEARITY	0.18%
ENCODER OUTPUT CODE	BINARY
NUMBER OF BIT	16
AIM ACCURACY	0.0017 rad
ZERO ADJUSTMENT	by dip switch

3. DATA ACQUISITION SYSTEM

As in the case of following control, the data acquisition sub-system is also governed by a microprocessor which carries out the following tasks:
  a) time reading at the instant it receives the stop signal from the PMT;
  b) telescope position reading;
  c) Reading of time interval recorded by the time interval counter;
  d) temperature, humidity and pressure sensor readings;
  e) Dialogue with computer personnel.
The clock is triggered by the 1 Mhz sample frequency of our Master Clock and therefore gives a resolution of 1 us.
Furthermore, the clock is equipped with an output at various frequencies for the laser control trigger.
Readings are carried out serially at the moment in which the stop signal is received from the photomultiplier in the order given above.

The entire system will be managed by an IBM or IBM compatible personal computer to facilitate the management of both the follow control and data acquisition sub-system and the files of data acquired during satellite rangings.

In Table 3 the salient characteristics of the system are described.

Table 3

DATA ACQUISITION SYSTEM FEATURES

CLOCK RESOLUTION	1 us
CLOCK PRECISION	not yet verified
PULSE TRIGGER FREQUENCY	1Hz-10Hz
HP COUNTER RESOLUTION	20 ps
HP COUNTER PRECISION	100 ps

Table 4
STATION SITE DATA

STATION NUMBER	9999 (Punta Sa Menta)
LATITUDE	39°08'32"
LONGITUDE	8°58'12"
ALTITUDE	202 m ssl
CAVU	Average 120 days an year

```
┌─────────────┐              ┌──────────────┐   YES
│   INPUT     │         ┌───>│   ALARM ?    │──────>  DISPLAY
│ EPHEMERIDES │         │    └──────────────┘
└─────────────┘         │           │ NO
       │                │           ▼
       ▼                │    ┌──────────────┐
┌─────────────┐         │    │ SEND ANGULAR │         MOTOR
│SEND POSITION│─────────┘    │    VALUES    │──────>  CONTROLS
│   WANTED    │<──────┐      └──────────────┘
└─────────────┘       │             │
       │  NO          │             ▼
       ▼              │ NO   ┌──────────────┐
┌─────────────┐       └──────│   POSITION   │<─────── ENCODERS
│RICEIVED STOP?│<───────────│  ACHIEVED ?  │
└─────────────┘       YES    └──────────────┘
       │ YES
       ▼
┌─────────────┐
│  READ DATA  │──────┐
└─────────────┘      │     ┌──────────────┐
       │             │<────│READ STOP HOUR│<─────── CLOCK
       ▼             │     └──────────────┘
┌─────────────┐      │
│   STORAGE   │      │     ┌──────────────┐
└─────────────┘      │<────│  READ MOUNT  │<─────── ENCODERS
                     │     │   POSITION   │
                     │     └──────────────┘
                     │
                     │     ┌──────────────┐
                     │<────│  READ ECHO   │<─────── COUNTER
                     │     │TIME INTERVAL │
                     │     └──────────────┘
                     │
                     │     ┌──────────────┐
                     │<────│    READ      │<─────── CLIMATIC
                           │  OTHER DATA  │         SENSORS
                           └──────────────┘
```
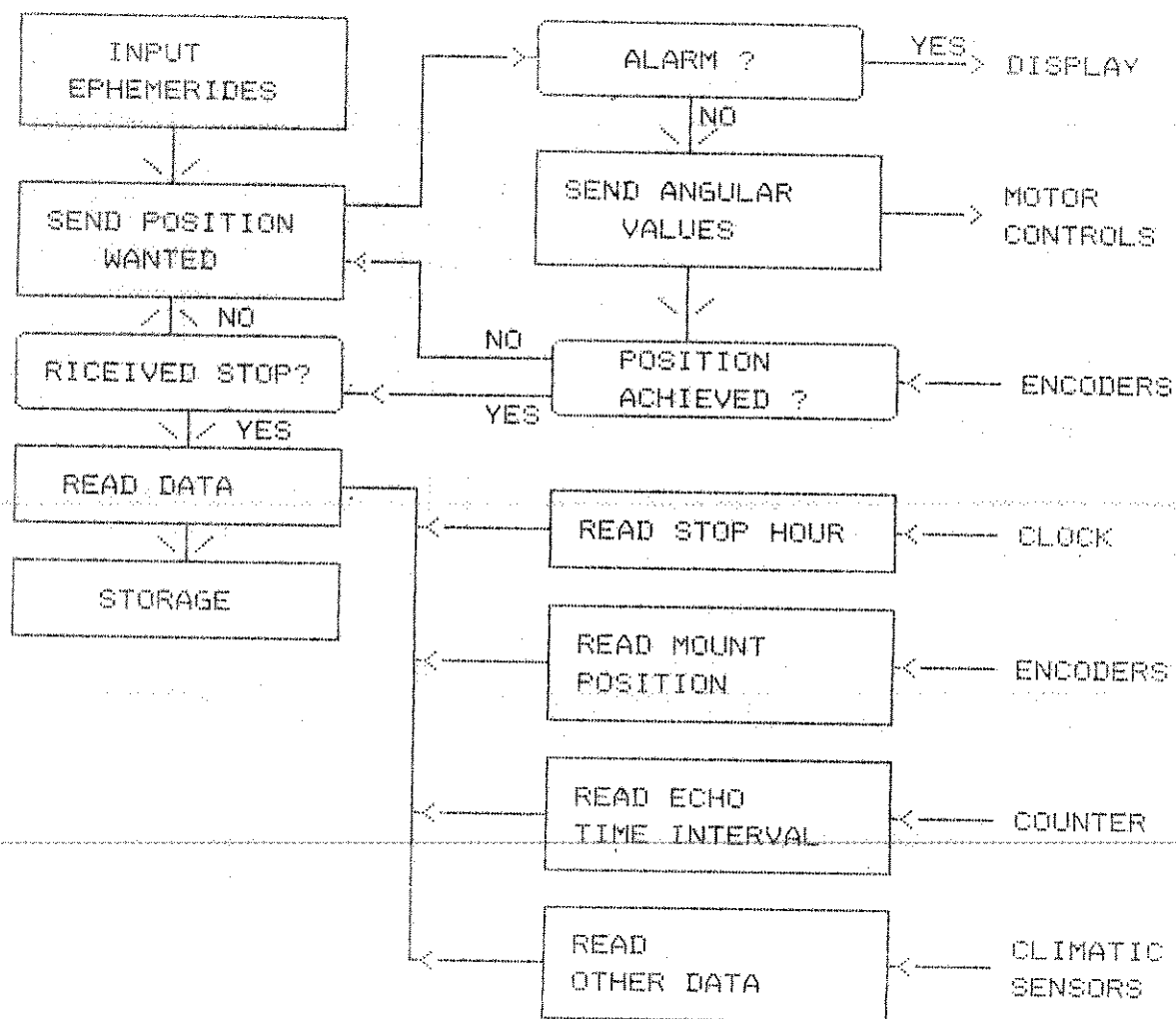
Figure 3
CONTROL PROGRAM FLOW CHART

ENC | 60/1 | T.D. | DC MOTOR

μP

EPHEMERIDES

CT CONTROL μP

MASTER CLOCK ————— 1 MHz ——→

LASER TRIGGER ——← 1Hz–2Hz ——

CLOCK & READER μP

PERSONAL COMPUTER

TIME INTERVAL COUNTER

INTERVAL ——→
START ——→
STOP ——→
RESET ——←

BEAM DET.

TIME
TIME INTERVAL
C.T. POSITION.

Figure 2
CONTROL BLOCK DIAGRAM

CAGLIARI LASER STATION

TRACKING SYSTEM

TIME SYNCHRONIZATION

LASER TRANSMITTER SYSTEM

ADRESSER

TIME INTERVAL COUNTER

1 MHz

C.F. DISCRIM.

CLOCK REGISTER

PHOTO MULTIPLIER

CESIUM MASTER CLOCK

TV MONITOR

CAMERA CONTROL UNIT

INTERFACE

RESULT SCANNER

ENCODER CARD

ENCODER CARD

INTERFACE

MOTOR SERVO AMPLIF.

PERSONAL COMPUTER OLIVETTI M24

TO Az MOTOR

TO El MOTOR

BEAM SPLIT

CAMERA HEAD

TELESCOPE 50 cm DIAMETER

Az MOT   E.C.

OUTPUT PULSE

El MOT ENC.

SIMERIGHI MASTER CLOCK

RECORDER

COMPAR

CAGLIARI OBS. Cs MASTER CLOCK

RECORDER

COMPARISON

COMPAR

RECORDER

TURIN I.E.N. Cs MASTER CLOCK

LORAN-C RECEIVER

TV

COMPAR

TV

COMPAR

OSCILL. 300 MHz

PHOTO DIODE

1J 5ns

TO PMT

ENERGY METER

CONTROL CONSOLE

0-15J AMPLIF. 15×13cm

1J 20ns SHUTTER

POWER SUPPLY

COOLING UNIT

OSCILLATOR 7.5×1cm

REFERENCE

Cugusi L., Messina F., Proverbio E.
A LASER RANGE TRACKING STATION FOR GEODYNAMIC SATELLITES
,Proceedings of the Second Workshop on Laser Tracking
Instrumentation, Prague 1975

Cugusi L.
THE SATELLITE LASER RANGING SYSTEM AT CAGLIARI OBSERVATORY
Proceedings on Third Workshop on Laser Ranging
Instrumentation, 1978

ZIMMERWALD SATELLITE OBSERVATION STATION

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1986 STATION REPORT AN ESTIMATE OF SYSTEMATIC ERRORS

1986 STATION REPORT AND ESTIMATE OF SYSTEMATIC ERRORS

ZIMMERWALD SATELLITE OBSERVATION STATION

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1.STATION REPORT AS PER SEPTEMBER 1,1986

LASER

Measurements proved that the emitted laser energy in the mean was never above 5 millijoules, a fraction of the permitted energy with the Quantel 402 DP laser. Yet already at this output level the KD*P doublers had to be reworked quite frequently. The reason for this is suspected insufficient mechanical stability, and possibly uneven energy profile of the beam.
The average frequency of the laser shots also was never up to th expected 9 Hz or so, but mostly lingered around 5 Hz. This in turn reduced data-yield. Active/passive mode-locking in the near future will improve this situation.
An unnoticed breakdown in primary laser cooling caused destruction of a ND-YAG window and consequently a break in observations between July and September 1985.
The pulse-selector (Krytron switch) proved unreliable and will be replaced by the end of this year.

TRANSMIT OPTICS

The lenses of the Galilei telescope were replaced by a more precise set with better coatings, thus affording better transmittance and far field.

RECEIVER

After the protective shutter had been installed, and 1 GHz bandwidth provided for the timing channel, the microchannel plate photomultiplier (Hamamatsu R1294U) was tried with some good results.
99% of the data, though, have been gathered with the conventional photomultiplier model D341B by EMI.
A HP5370A time interval counter was purchased in spring 1986 and added to the system. Due to the computer limitations mentioned

below, it could be used only for calibration purposes so far.
Intercomparison with our time digitizer showed a small reduction
in digitizing noise, but no noticeable difference in systematics.

COMPUTER
The software was extended by some degree; most prominent extensions were the possibility of communicating via GE-Mk 3 (making
telex transmission of QL data obsolete), improved tracking support and data screening.
The station computer PDP/11-40 under RT-11 and only 64 kbyte of
RAM limited the program evolution , and many new concepts could
not yet be implemented. Because of this, and the increasing failure rate, we decided to introduce a new computer, most possibly
during 1987.

TIME SYSTEM
The station was fitted with a BVA quartz oscillator as principal
time-base. This type of oscillator is reported to yield the best
short-time stability.

OPERATIONS
Tracking efforts were considerable, but yields moderate. The
wheather limited observations, as well as the bad nocturnal
coverage by LAGEOS in summer 1986. Much time was put into
calibrations, to finally be able to specify an error budget.
Some special efforts were taking place in the fall of 1985, when
the dutch MTLRS was visiting Mte. Generoso in southern Switzerland. SLR, terrestrial LR and GPS observations were gathered.
Results are presently under review.

FUTURE IMPROVEMENTS AND ADDITIONS

The modifications of the laser for active/passive mode-locking
and spatial filtering are under way. The computer replacement
(most probably by a DEC Microvax) and an exchange of angle-encoders will be the most prominent upgrades at the station in
1986/7. We also hope, by modification of the building structure,
to gain space for a new laser table. The purpose is to rearrange
the laser related equipment to facilitate a mechanically more
stable setup, and to solve the radio interference problem into
the electronic system.

2. PRECISION ESTIMATE OF ZIMMERWALD LRS
This summary report covers the period September 1984 through
August 1986. More detailed information is available on request.

2.1 MODELLING AND ENVIRONMENTAL ERRORS
The survey error is not being specified because we describe a
stationary system.
Refraction corrections are especially sensitive to the pressure
measurement. From barometer trips from the State Standards
Laboratory, we conclude that the mercury barometer at our
station is not beyond doubt. This situation is being cleared,

and for the reported period a worst case estimate used.[1] No
measurements are made below 30°.

2.2 RANGING MACHINE ERRORS
SPATIAL VARIATION
No test of this has been made due to the lack of external calib-
ration. We trust that our mode-locked QUANTEL laser performs
equal to those tested at GSFC.Any remaining spatial effect
should tend to average out due to our rather erratic tracking.

TEMPORAL VARIATION
As we perform in-pass calibration, temporal effects are
minimized. However, the calibration measurements have been
averaged over the whole pass so far. The mean has been rounded
to 1/10 of a nanosecond, introducing a rounding error which
should not introduce systematics.

AMPLITUDE DEPENDENCE
The system was mostly operated in the 1-10 photon region
(LAGEOS).Stronger returns were noticed on the display and the
beam immediately widened, thus limiting time-walk. Any excess
amplitudes could be detected after screening and appropriate
measures taken.

CALIBRATION PATH
The internal path geometry can be sufficiently well measured. On
the other hand there is a piece of optical fibre for feedback ,
the delay of which has to be measured electro-optically. The
method employed ensures an uncertainty of less than 100 pico-
seconds (a value which can be improved in the future.)

CALIBRATION (METEOROGICAL CONDITIONS)
Not applicable because of internal calibration.

MOUNT MODEL
Mount eccentricity is removed by the internal calibration.

TIMING ERRORS
Daily TV comparisons ensure an accuracy of ∓1 microsecond; an
additional allowance is made for the drift of the TV delay-
constant, which is checked yearly by clock transport. Since this
method allows only "a posteriory" time comparison, the QL data
epochs are of LORAN accuracy. (∓ 5 µs worst case).

We finally wish to remark that we miss a specification of the
short-time stability of the flight-time clock (scale factor) !
We urge that this issue be discussed at the next opportunity !

[1]Note: A fault in the mechanical readout of the barometer has
been found meanwhile; no adjustment is made of the data because
the error was judged negligible.

RANGING ERRORS (CM)

	PASS	DAY	MONTH	INDEF.
MODELLING ENVIRONMENTAL ERRORS				
ATMOSPHERIC PROPAGATION (MODEL)	.5	.5	.5	.5
ATMOSPHERIC PROPAGATION (METEOROLOGICAL MEASUREMENTS	1.0	1.0	1.0	1.0
SPACECRAFT CENTER OF MASS	.2	.2	.2	.2
GROUND SURVEY OF LASER POSITION	–	–	–	–
DATA AGGREGATION	–	–	–	–
R.S.S.	1.2	1.2	1.2	1.2
RANGING MACHINE ERRORS				
SPATIAL VARIATION	1.0	.5	.5	.5
TEMPORAL VARIATION	1.0	.3	.1	.1
SIGNAL STRENGTH VARIATION	3.0	3.0	3.0	3.0
CALIBRATION PATH (SURVEY)	1.5	1.5	1.5	1.5
CALIBRATION PATH (METEOROLOGICAL CONDITIONS)	–	–	–	–
MOUNT ECCENTRICITIES	.1	.1	.1	.1
R.S.S.	3.70	3.50	3.40	3.40

RANGING ERRORS (CM)
TIMING ERRORS (MICROSEC)

PORTABLE CLOCK SET	1.0	1.0	1.0	1.0
BROADCAST MONITORING	1.0	1.0	1.0	1.0
R.S.S.	1.5	1.5	1.5	1.5

ESTIMATED RANGING ERRORS FOR SATELLITE LASER RANGING SYSTEM
ZIMMERWALD LRS (7810) 1984-1986
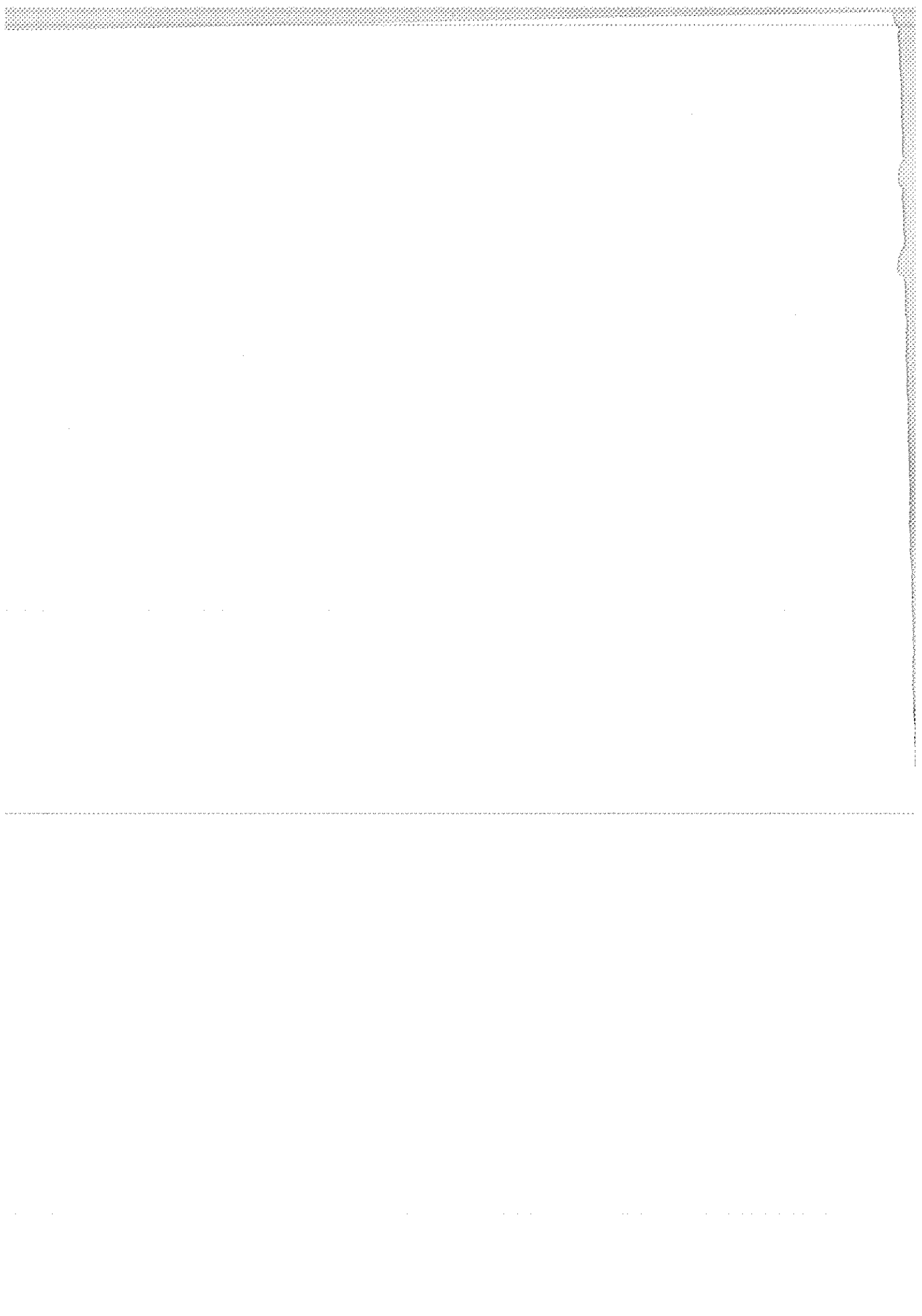
THE NEW CERGA LLR STATION

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ABSTRACT

The new Cerga Lunar Laser Ranging station is presented with its main characteristics. The new YAG laser delivers at 10 Hz two beams 300mJ each in green with a 300 ps pulse. The new transmitting/receiving/pointing package is described as well as the computer environment. The first series on a single night (obtained after the workshop) are finally shown.

1/ Introduction

The CERGA LLR station has been operating for four years with results increasing both in quantity and quality. It used a ruby laser with a 3ns/3J pulse and 10 shots per minute. Fig. 1 shows the progression in data quantity and diversity (various reflectors ...). Since April 1984, the normal point accuracy has been stable around 16 cm on the Moon distance. The CERGA station has been the most productive in 1985, and more than 2/3 of the UT determinations made from LLR that year have used CERGA data.

LEGEND:
- Apollo XI
- Apollo XIV
- Apollo XV
- Lunakhod 2
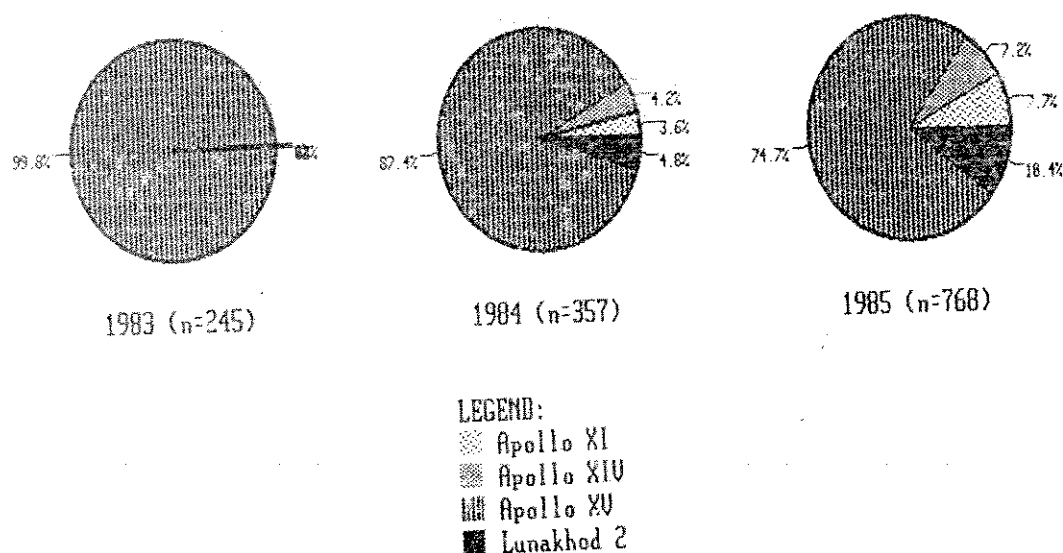
Fig. 1 - Normal point total number and repartition over reflectors - *n is the number of normal points obtained with the old ruby laser at the CERGA LLR station for the given year.*

In order to improve the accuracy of the data, an upgrade on two years has been planned for 1985 and 1986, including a new computer, a new laser and the new transmitting/receiving equipment linked to different laser rate and wavelength.

2/ The laser

Fig. 2 shows the implementation of the new Quantel Nd-YAG laser components on the granite. The oscillating cavity can work in both active/passive (dye cell) or active/active modes. After the slicer, each pulse is 1 mJ in 300 ps in active/active mode, or roughly .4 mJ in 200 ps in active/passive mode, both at a 10 Hz pulse rate and in infra-red. Two consecutive 7mm rod amplifiers permit to reach 200 mJ in active/active mode. This pulse is divided in two equal pulses, both of them being finally amplified on its own third amplifier (9mm rod), a delay line insuring a simultaneity of the start at the granite edge. The final energy is 600 mJ in infra-red per 300 ps pulse and per beam at 10 Hz.

By changing the Fabry-Perot glass at the cavity output edge, other pulse lengths in active/passive mode can be obtained down untill 35 ps. They can be used for exemple for accuracy tests on the electronics. If the active/active mode is easier to work with (there is dye check and maintenance), it is less stable in energy. This mode has been used at the beginning till December 1986. The active/passive mode is now used due to a much better stability.
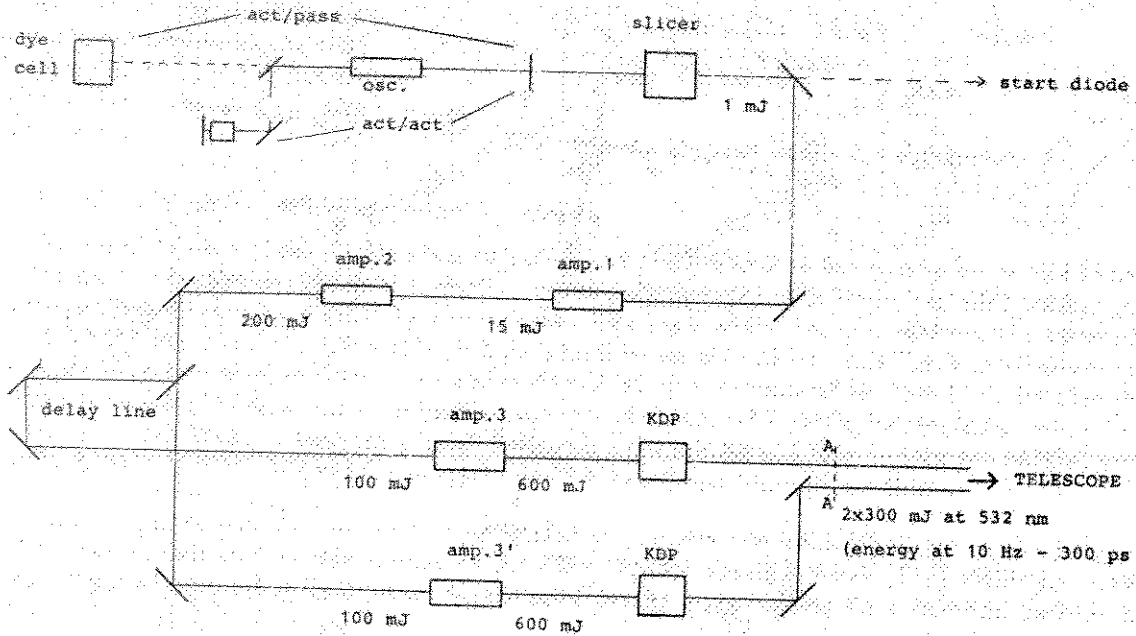
Fig. 2 - Laser configuration - *Energies are given at 10 Hz rate for 300 ps pulses.*

The shape of the two beams at the edge of the laser and on the telescope aperture can be seen on Fig. 3. Each beam has a 9 mm diameter after the last amplifier. The two beams are made parallel at the laser edge with a 9 mm separation. At the matching lens level, the laser spots are tangent and roughly 15 mm wide. This double beam configuration has been chosen in order to increase by a factor 2 the emitted energy without increasing the risks of damaging the optical components, and for only 20% of laser total cost.
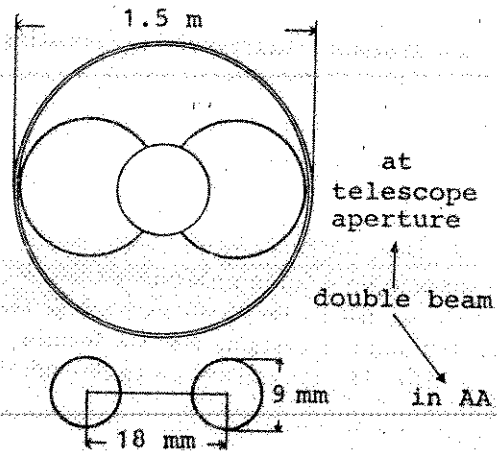
Fig.3 - Double beam configuration

3/ The transmitting/receiving/pointing package

The general design of this package is shown on Fig. 4. This system is mounted on the telescope and is moving with the telescope azimuthal motion. It has been designed in order to minimise the number of optical components encountered by the returns. The transmitted beam is entering the telescope after the matching lens (ML) and a reflection on a rotating mirror (RM1). This mirror itself starts the laser when in transmission position. Its speed is monitored by the computer in order to insure that the returns are entering the receiving path through the hole of the second rotating mirror, in fact a rotating hole (RM2). RM2 allows to send the pointed field on a CCD camera and then to view the pointed area on a TV screen when RM1 is not transmitting nor RM2 receiving (most of the time).

A diaphragm adjustable from 5 to 60" is located at the telescope focus (F) on the return path. A dichroic glass (D) sends the green returns on the PMT through the filter wheel (FW) within an afocal system. The red way is free in R where an eye-piece can be used, waiting for a receiving package at 1.06 m.
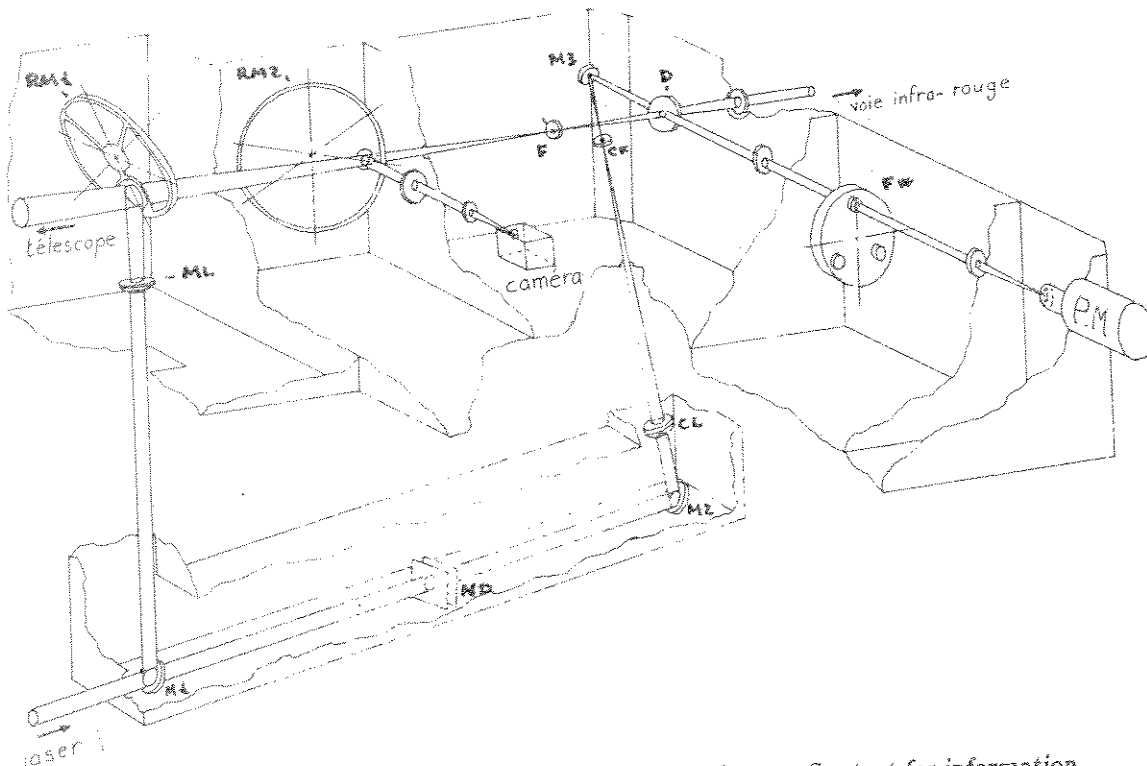
Fig. 4 - Transmitting/receiving/pointing package - *See text for information.*

The internal calibration path is shown on the same figure. The light transmitted by the first mirror M1 (lower left) is sended on the receiving package through neutral densities (ND) for attenuation, a second mirror M2 and a converging lens CL focusing the calibration in a point CF conjugate of the telescope focus. After M3, the calibration go through the dichroic glass (D) and follows the return path till the PMT.

4/ The computer and its environment

The new computer (PDP 11/73) has been installed in September 1985 and has monitored the ruby station ten months before the laser change. Its environment is shown on Fig. 5. The main characterictics of the configuration is that the PDP is not concerned with telescope pointing and guiding. At the beginning of each observing session, the data needed for pointing the Moon (9 reference craters and the five reflectors) and close stars are sent from the PDP to a microcomputer Victor S1. This small computer is sufficient for running the telescope for all the night with a very friendly software.

The PDP is thus only busy with the real time monitoring of the station : rotating mirrors enslavement, event acquisition (laser starts, internal calibration and in gate events), gate commands, ... The event-timer has one channel for the laser start and three other for events (calibration or/and gate events). Its resolution is 50 ps. A link is planned between the PDP and a CCD camera used for pointing stars or features on the Moon. It could be used for an automatic pointing (planned for the end of 1987). A data processing is made at the end of each series providing with the normal point (if there are identified returns). At the end of the night, these data can be used for a UT0 determination.
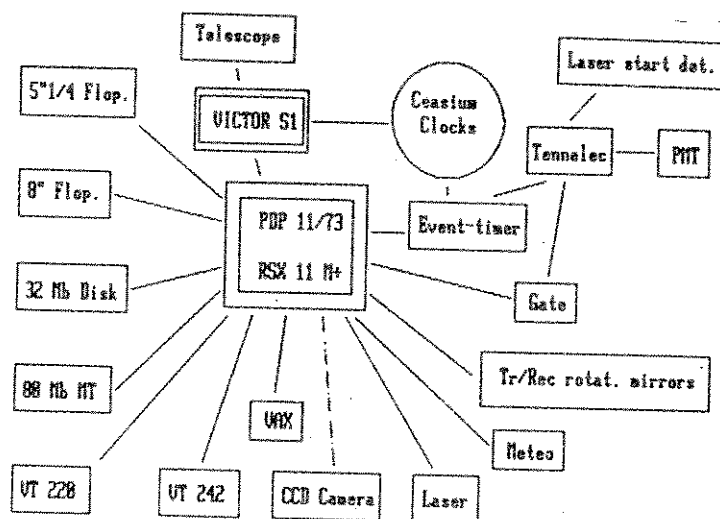

Fig.5 - Computer environment

The PDP is linked to the VAX computer located at the CERGA down and the normal points can be sent from the station on the VAX and from there on the CNES CDC computers.

5/ Conclusion

The system described here is working since the end of September 1986. It is planned to spend 6 months to test and improve the various components of the station recently modified or changed (laser, electronics, mechanics and software). It is thus too early to give some conclusions on the efficiency of the new station. The next paragraph added after the workshop will show the first results, but no information on energy or error budgets can be extracted from these data. The PMT, the laser and the internal calibration were not at there normal efficiency ... and the timing electronics was not tuned at this time for minimal jitters and biases.

The year 1987 should proof the quality both in accuracy and in efficiency that we hope to have with this new LLR station.

6/ First results ...

Fig. 6 shows a plot of the residuals for four normal points obtained in November 1986 (ns on the round-trip). The dotted line shows the fit done to determine UT0 from thes data. It can be seen that the prediction used for the observations was very poor. The value finally found using X and Y prediction from BIH is :

$$UT0 - UTC = -0.09024 \text{ s} \quad (\sigma = .00127) \quad \text{at} \quad JD = 2446759.673591$$

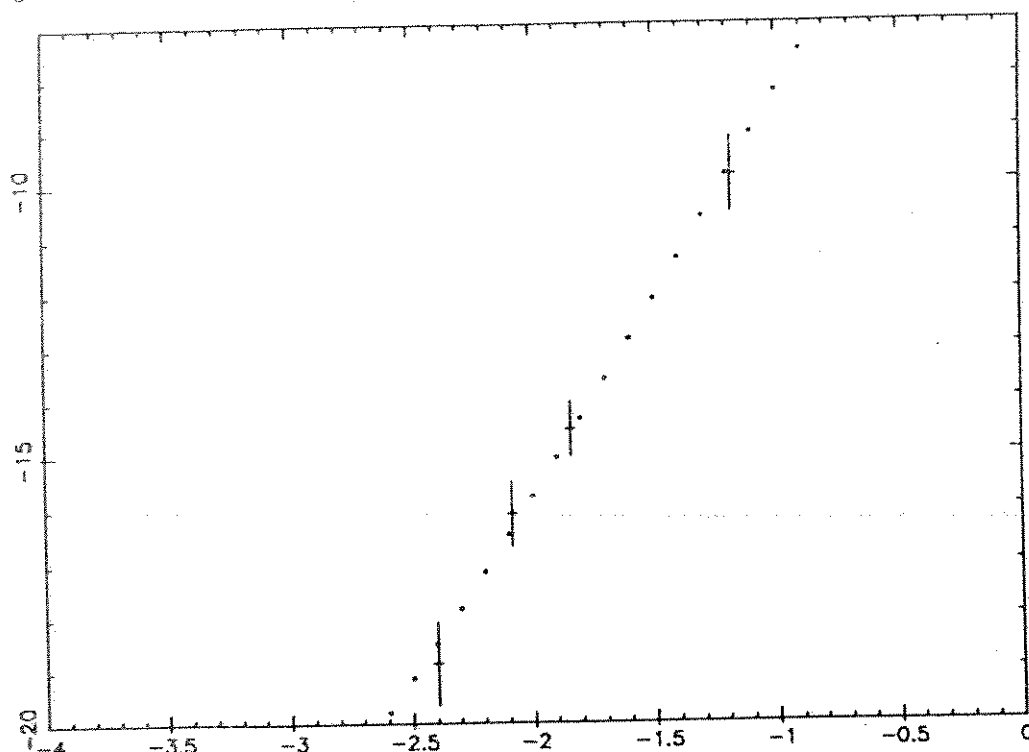The weighted rms of the residuals is 4.5 cm on the Moon distance.

Fig. 6 - First normal point residuals - November 1986 - Residuals for four normal points in ns relative to the hour angle of the Moon (in hr). See text for more information